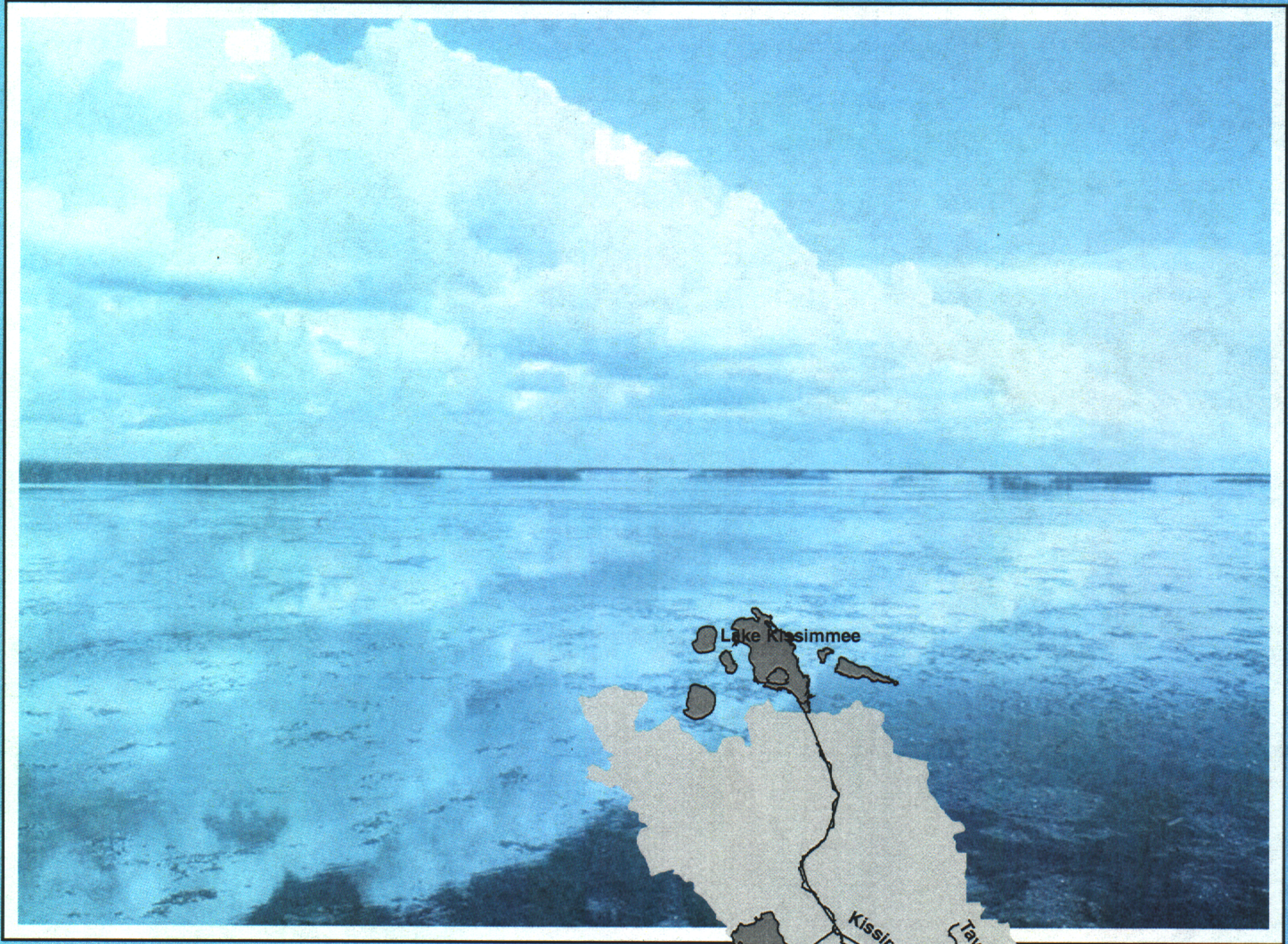
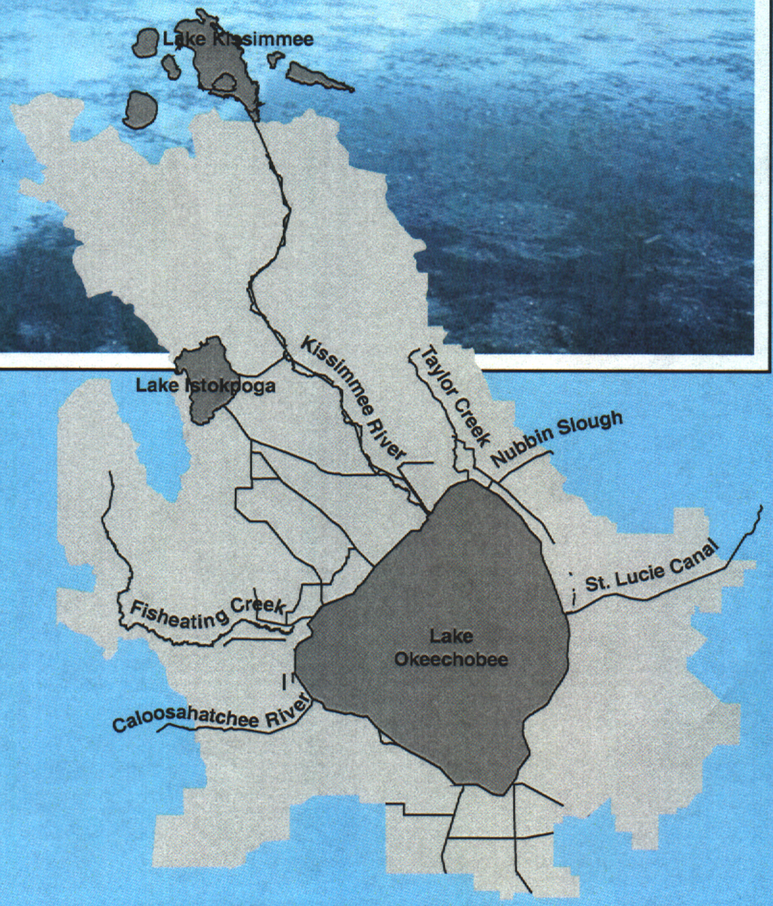
LAKE OKEECHOBEE PROTECTION PROGRAM

January 1, 2004

Annual Report to the Legislature





South Florida Water Management District

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Lake Okeechobee Protection Program – Annual Report to the Legislature
January 1, 2004

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1.0 Overview of Lake Okeechobee Protection Program

The Lake Okeechobee Protection Act (LOPA, Chapters 00-130, Laws of Florida) was passed by the 2000 Legislature. This Program committed the State of Florida to restore and protect Lake Okeechobee. This will be accomplished by achieving and maintaining compliance with water quality standards in Lake Okeechobee and its tributary waters, through a watershed-based, phased, comprehensive, and innovative protection program designed to reduce phosphorus loads and implement long-term solutions, based upon the Lake's Total Maximum Daily Load (TMDL). The Program sets forth a series of activities and deliverables for the coordinating agencies: the South Florida Water Management District (hereafter, District); the Florida Department of Environmental Protection (hereafter, FDEP); and the Florida Department of Agriculture and Consumer Services (hereafter, FDACS). This is the fourth annual report to the Legislature, summarizing the water quality and habitat conditions of the Lake and its watershed, implementation activities of the past year including the status of the Lake Okeechobee Construction Project, challenges, and unresolved issues. A companion report, the Lake Okeechobee Protection Plan (LOPP), identifies areas requiring future legislative support to successfully implement the State's commitment to protect and restore this resource.

2.0 Description of Lake Okeechobee and the Watershed

2.1 Lake Okeechobee

Lake Okeechobee is a large, shallow, eutrophic lake located in south central Florida. The Lake is the largest body of freshwater in the southeastern United States and covers a surface area of 730 square miles, with an average depth of 8.6 feet. It is encircled by an embankment that is approximately 140 miles long with crest elevations ranging from 32 to 46 feet NGVD (URS, 2002). Lake Okeechobee functions as the central part of a large, interconnected aquatic ecosystem in south Florida and as the major surface water body of the Central and Southern Florida Flood Control Project. The Lake provides a number of values to society and nature including water supply for agriculture, urban areas, and the environment; flood protection; a multi-million dollar sport and commercial fishery; and habitat for wading birds, migratory waterfowl, and the federally endangered Everglades Snail Kite. These values of the Lake have been threatened in recent decades by excessive phosphorus loading, harmful high and low water levels, and rapid expansion of exotic plants.

2.2 Specific Issues of Concern

2.2.1 Water Quantity

- Water levels in the Lake have now been above 15 feet NGVD for over 14 months, with only a short drop below that high level in the early summer.
- A large number of pulse releases were made from the Lake to the St. Lucie and Caloosahatchee Estuaries, in an attempt to minimize rising

lake levels and reduce the risk of higher volume steady-flow regulatory discharges to those downstream ecosystems.

- Despite these pulse releases, it became necessary to implement steady-flow regulatory releases in late August, due to continued rises in lake stage and increasing concerns regarding flood protection issues.
- The large releases of freshwater from the Lake had adverse impacts on water quality and biota in the estuaries; but now that these regulatory discharges have stopped, salinity has recovered in these ecosystems.
- Although these adverse conditions occurred, the Lake's current regulation schedule (WSE = Water Supply and the Environment), adopted in the summer of 2000, kept the Lake approximately 1 foot lower at its peak winter stage than would have occurred under the previous schedule.

2.2.2 Ecological Attributes

- The prolonged high water levels have resulted in substantial losses of shoreline bulrush, grass beds, and submerged plants (Figure 1). The total acreage of submerged plants this year is just 70 percent of what was documented in 2002, and further losses are expected to occur.
- Algal blooms have been common in the Lake this year; and with the deep water, have even occurred in areas that still had dense beds of plants. Once the water depth reaches a certain level, plants are not able to effectively control water column nutrients; and noxious blooms can occur.
- Berms of organic material have accumulated along the Lake's north and northwest shorelines, similar to what happened in the Lake in the late 1990's after a period of high water levels.
- Losses of plant communities are expected to have negative impacts on invertebrates, fish, wading birds, and other biota that use the Lake for habitat.
- In summary, the overall health of the Lake seriously declined from 2002 to 2003, due to sustained high levels of water.

2.2.3 Water Quality

- Total phosphorus concentrations in the Lake have more than doubled since the early 1970's, now averaging more than 120 parts per billion (ppb).
- There is a high rate of phosphorus loading to the Lake from both the watershed (external loads) and from the mud sediments within the Lake (internal loads).
- In 2002, the annual load to Lake Okeechobee was 543 metric tons (Mtons). The five-year average phosphorus load from 1998 to 2002 was 554 Mtons and exceeded the Lake Okeechobee TMDL by 414 Mtons (Table 1). This five-year average included the smallest measured historical load (169 Mtons in 2000), due to the worst drought in recent history; and the largest measured load in the past decade (780 Mtons in 1998), due to a very wet year. These extremes

document the reason that the TMDL is based on a five-year average, to account for variations in water flow and loads. This variation can occur rather rapidly. The measured load shown for 2003 represents only six months, and it reflects a period of relatively low flow. In contrast, high flows occurred in the late summer of 2003, so the yearly load will likely be significantly higher than twice the measured load shown for 2003.

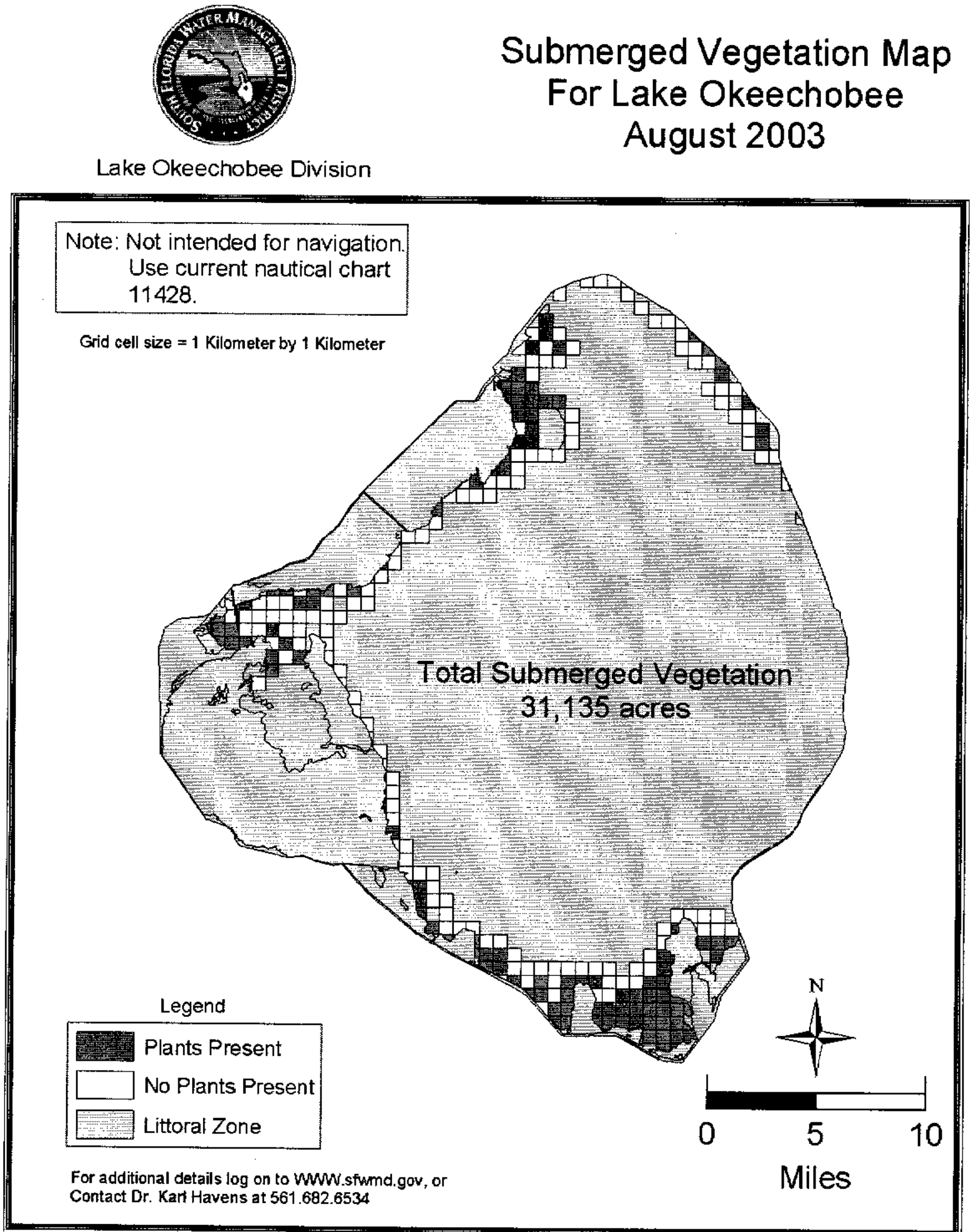

Figure 1. Submerged Vegetation Map for Lake Okeechobee (8/03)

Table 1. Total Phosphorus Loads (in metric tons) to Lake Okeechobee 1991-2003

Year	Measured Load [a]	Long-term Load (5-yr moving average) [a]	Long-term Over-target Load (5-yr moving average) [ab]
1991	445	415	275
1992	388	393	253
1993	296	375	235
1994	580	421	281
1995	683	478	338
1996	200	430	290
1997	470	446	306
1998	780	543	403
1999	670	561	421
2000	169	458	318
2001	607	539	399
2002	543	554	414
2003	187 [c]		

[a] Measured Loads include an atmospheric load of 35 metric tons per year based on the Lake Okeechobee TMDL (FDEP, 2001)
[b] Target load is the Lake Okeechobee TMDL of 140 metric tons (FDEP, 2001) compared to a five-year moving average.
[c] Year 2003 data reported is through June of 2003 and includes only 6 months of the annual atmospheric load. The QA/QC process for the data for the complete year will not be complete until March of 2004.

3.0 Ongoing Projects Required by the Lake Okeechobee Protection Program

3.1 Watershed Phosphorus Control Programs

3.1.1 Agricultural Programs

3.1.1.1 FDACS Lake Okeechobee Watershed Agricultural Best Management Practice Phosphorus Control Program

A considerable effort has been expended in 2002 and 2003 on the implementation of agricultural Best Management Practices (BMPs) to immediately impact the watershed's phosphorus discharges to the Lake.

The coordinating agencies agreed that the first step to successfully control phosphorus is to develop a tool to determine specific on-farm current and future phosphorus sources. The development of this tool, called an Agricultural Nutrient Management Assessment (AgNMA) was completed in 2002. AgNMAs were completed for all active dairies in the four priority basins of the Lake Okeechobee watershed (S-191, S-154, S- 65D, and S-65E), representing over 29,400 acres (Figure 2). An additional 3,800 acres of former dairies have also had nutrient management assessments completed. Once the specific on-farm current and future

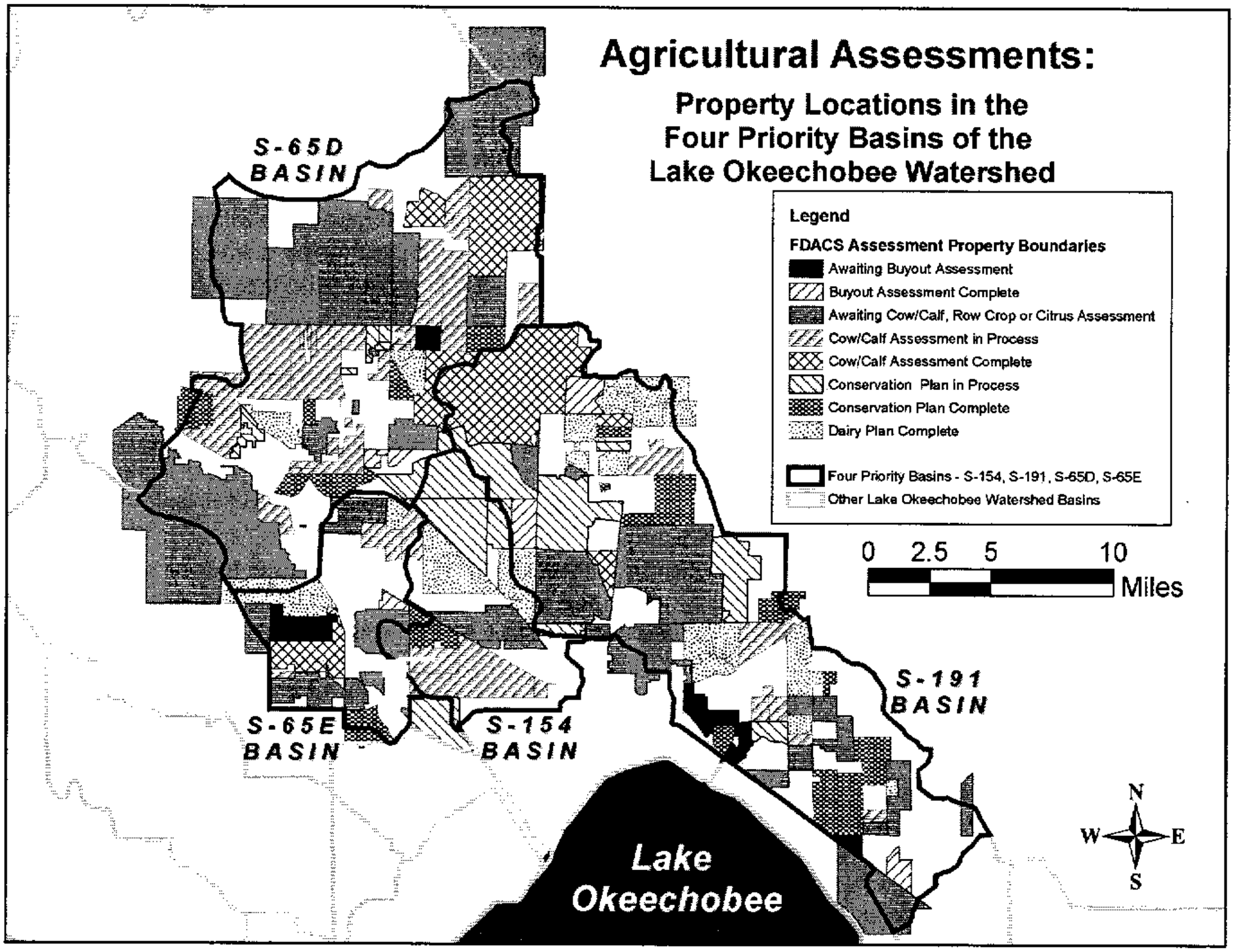

Figure 2. Area of Landowner Participation in the Four Priority Basins in the Lake Okeechobee Watershed.

phosphorus sources were identified, Agriculture Nutrient Management Plans (AgNMPs) were completed for each dairy. The two goals of the AgNMPs were whole-farm nutrient balance and an edge-of-farm phosphorus discharge concentration of 150 ppb. Each dairy shared common phosphorus sources, but each also had unique circumstances. The AgNMPs indicated that it would cost a total of $105 million to achieve both of these goals for all dairies in the watershed.

Cow/calf assessments and interim measure plans have been completed on 17,200 acres, with an additional 19,300 acres of cow/calf operations and 6,700 acres of former dairy operations in the planning process. Cow/calf production is the largest agricultural land use in the Lake Okeechobee watershed, and it is anticipated that the implementation of BMPs identified by Conservation Plans will substantially improve water quality in the watershed. Conservation Plans have been completed on over

20,800 acres of cow/calf operations, with another 61,600 acres currently in the planning process. These plans are being coordinated with the United States Department of Agriculture–Natural Resources Conservation Service (NRCS) to expedite the agricultural BMP planning effort. It is projected that these cow/calf properties will have completed the planning process by the end of December 2003. Over 25 additional cow/calf producers within the four priority basins, representing 84,200 acres, have also agreed to participate in the process. Collectively, these activities cover 243,074 acres or 85 percent of the agricultural acreage in these four priority basins (Figure 2).

In a cooperative effort, FDACS and NRCS have obtained a federal appropriation of $500,000 to further advance conservation planning in the Lake Okeechobee watershed. These funds will be used to identify and train technical service providers and conservation planners who are willing to work in the Lake Okeechobee watershed to develop Conservation Plans for cow/calf operations. FDACS has contracted with Environmental Management Solutions (EMS), a certified technical service provider for services related to the expedited conservation planning effort.

FDACS and NRCS have executed an Interagency Memorandum of Agreement that commits the available resources within the two agencies to hasten delivery and implementation of nutrient and conservation management planning to agricultural landowners in the watershed. To accelerate the development of Conservation Plans in another effort, FDACS has contracted with the University of Florida – Institute of Food and Agricultural Sciences (IFAS) to provide training for third-party vendors who wish to participate in the development of nutrient management and/or Conservation Plans.

In addition to leveraging state and federal dollars for planning and cost-share programs, FDACS and NRCS have worked cooperatively with other partners to prepare a Public Law 566 (PL-566) Small Watershed proposal through NRCS that has been submitted for consideration by Congress. The PL-566 proposal, if approved, would greatly increase the amount of federal funding available for BMP planning, implementation, and cost-share in the lower Kissimmee and S-191 (Taylor Creek/Nubbin Slough) basins. If accepted, these activities would begin in 2004.

FDACS has developed and adopted an administrative rule (5M-3) that adopts BMP manuals for citrus producers and cow/calf operations and AgNMAs for dairy operations, and discusses the process for implementing these BMPs. FDACS is developing a non-regulatory incentive-based BMP implementation program for other agricultural activities, including vegetables and row crops, modeled after the Indian River Lagoon Citrus BMP Program.

Through this rule, the implementation of an FDACS farm assessment, Notice of Intent to implement a BMP plan, or an NRCS Conservation Plan will provide the landowner with a presumption of compliance with state water quality criteria. Landowners who choose not to participate in the FDACS BMP programs will be required to monitor the quality and quantity of water leaving their properties to demonstrate compliance with existing and future phosphorus targets and requirements through the District's Works of the District (WOD) permitting program.

3.1.1.2 Best Available Technologies

In October 2000, the District initiated the Dairy Best Available Technologies project to identify, select, and implement Best Available Technologies (BATs) to significantly reduce phosphorus loading from dairy operations in the Lake Okeechobee watershed. After a thorough evaluation of alternatives by an Interagency project team, edge-of-farm stormwater treatment was selected for implementation on three dairy properties in the Lake Okeechobee watershed (Figure 3). These projects consist of capturing

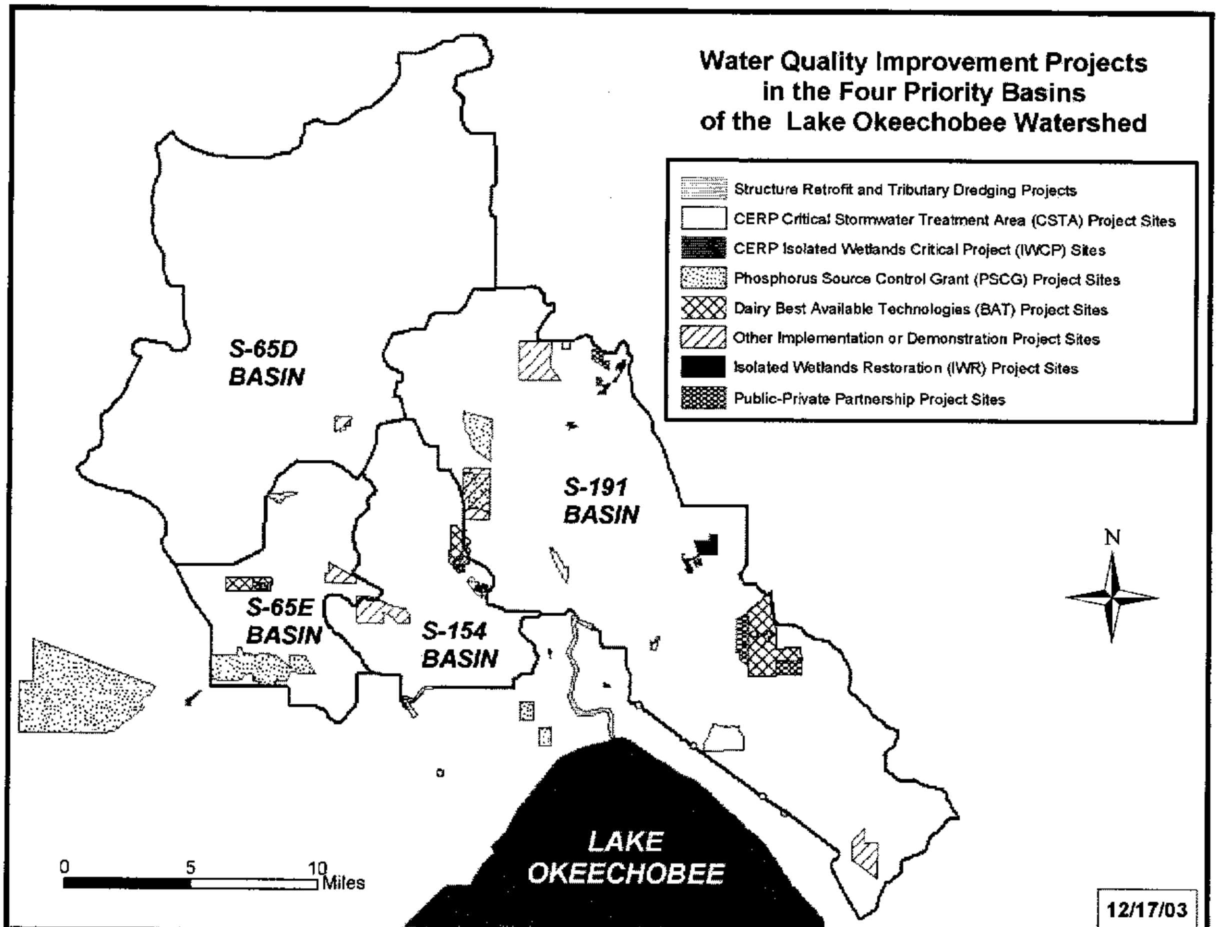

Figure 3. Water Quality Improvement Projects in the Four Priority Basins of the Lake Okeechobee Watershed

stormwater runoff (especially from all of the high nutrient pasture areas); reusing the runoff on-site in current operations if possible; and if off-site discharge is necessary, chemically treating the stormwater prior to its release. The three Dairy BATs project sites are currently under construction and are anticipated to be completed by January 2004. Phosphorus load monitoring is a component of the project, so that performance can be accurately determined. Project performance will be evaluated at various total phosphorus discharge concentration goals ranging from 150 ppb to 40 ppb. Annual phosphorus load reductions could range from 80 to 90 percent.

FDEP provided funds from the 2002-2003 State general revenue funds designated for TMDL implementation projects to be used for the design and implementation of a fourth dairy BAT site. The coordinating agencies are currently developing the design of the next site and will begin construction by March 2004.

3.1.1.3 Isolated Wetlands

The Lake Okeechobee Isolated Wetland Restoration Program (LOIWRP) is designed to restore the amount and timing of stormwater runoff to a wetland, which will reduce the amount of phosphorus discharged from parcels to Lake Okeechobee. Historically, isolated wetlands covered a significant percent of land area in the four priority basins, capturing stormwater runoff and helping to retain phosphorus in the watershed. However, many of these wetlands have been drained to get more land into agricultural production, allowing more phosphorus to reach Lake Okeechobee. The LOIWRP is designed to reduce phosphorus discharge from land parcels to Lake Okeechobee through wetland restoration. There are currently about 44,902 acres of restorable wetlands in the four priority basins. The LOIWRP estimates approximately 1,635 acres of wetlands will be restored through this program with a drainage/treatment area of 3,922 acres; this will notably reduce phosphorus loads to Lake Okeechobee.

As a cost-share program, the LOIWRP pays for all wetland restoration costs including land survey, design, permits, construction, initial exotic and nuisance plant removal, fencing, and monitoring; plus the value of the easement. The landowner will be responsible for paying property taxes and for the operation and maintenance of the restored area. Landowners have the choice of entering into a 30-year or perpetual easement agreement for the portion of their property that is enrolled into the Program. The District is administering the LOIWRP with the cooperation of a multi-agency team which includes FDACS, FDEP, NRCS, United States Fish and Wildlife Service, and IFAS. The Program currently has a total of six projects, two in the design or construction phase (Kirton Ranch and McArthur Dairy) and three in the planning stage (Williams Ranch, State-Owned Property, and Hazellief Ranch) (Figure 3).

Several other wetland restoration or enhancement programs outside the LOIWRP are available for landowner participation. University of Florida staff are leading an Interagency team to develop a Wetland Enhancement Program, which will assist a landowner in selecting a wetland program that fits best with the landowner's operations. The Program is funded through the United States Department of Agriculture's Cooperative State Research, Education, and Extension Service (CSREES) Competitive Grants in the National Integrated Water Quality Program and puts together a comprehensive list of all programs available for wetland restoration in the Lake Okeechobee watershed. Landowners will be more fully educated on their options; and, therefore, participation in the various programs should increase, resulting in more restored wetlands and improved water quality.

3.1.1.4 Former Dairy Remediation

In 1989, the Dairy Buy-Out Program was established upon request by the dairy industry for farmers who were unwilling or unable to comply with FDEP (formally FDER) Dairy Rule by implementing BMPs as mandated. The Dairy Buy-Out Program did not purchase the property or cows, but simply facilitated removal of the animals. Of the 49 original dairies that existed in the Lower Kissimmee River and the S-191 (Taylor Creek/Nubbin Slough) basins before implementation of the Dairy Rule, 18 participated in the Dairy Buy-Out Program. A total of 14,039 milking cows were relocated under this Program, or were removed from the watershed for other reasons. These former dairies have a high amount of residual phosphorus in the soil.

Many of the former dairies are now privately-owned cow/calf operations and are currently discharging water that is out of compliance with the District's WOD program (i.e. they are discharging above the SWIM limit).

The District-owned former Lamb Island Dairy is currently being remediated under the Lamb Island Dairy Remediation Project. Lagoon remediation, stormwater runoff detention/retention, and wetland enhancement are the primary activities being implemented. Remediation projects are also being planned for five privately-owned former dairies that are now cow/calf operations. The goal of the remediation is to implement practices and technologies that will reduce the phosphorus surface water discharge to 150 ppb or less from the former dairies, based on information presented in the AgNMA. An Interagency team will be participating in the design, implementation, and evaluation of the restoration projects.

3.1.1.5 *Regulatory*

Works of the District Permitting

In 1989, the District produced the Lake Okeechobee Surface Water Improvement and Management (SWIM) Plan, pursuant to Sections 373.451 and 373.4595, Florida Statutes, which identified Lake Okeechobee as a priority water body threatened by excessive phosphorus loading. The primary source of phosphorus loading to Lake Okeechobee was found to be agricultural, non-point source runoff from its northern drainage basins. The resulting in-lake phosphorus concentrations upset the balance of natural flora and fauna of the lake ecosystem. In response, the District enacted the WOD permitting program.

The WOD program was designed to identify high phosphorus source areas and to bring them into compliance. It functions by permitting and monitoring parcels in 14 of the 31 "controllable" tributary basins (the 14 priority WOD basins, Figure 4) in the Lake Okeechobee watershed that exceeded the SWIM total phosphorus discharge concentration limit of 180 ppb to the Lake when the SWIM legislation was enacted.

This past year progress was made on restructuring the WOD monitoring program to complement the FDACS BMP program. Rather than continuing to monitor phosphorus concentrations at the parcel level, a micro-basin monitoring network was developed and implemented. This allowed the District to redirect its limited monitoring resources to cover a larger portion of the watershed. Data from the District's monitoring network will be used to provide information to FDACS so that they can appropriately direct their resources to bring parcels into the BMP program. Areas with high phosphorus concentrations are a priority.

In addition to restructuring the monitoring network, the WOD staff reviewed the FDACS Notice of Intent to implement BMPs and entered them into the District's tracking system. Individual and General WOD permits were issued. For those permits associated with a change of land use, phosphorus budget information was evaluated to ensure that phosphorus loading would not increase to more than that of the existing land use. Also, outreach activities were conducted to provide information on methods to improve water quality and implement BMPs.

Dairy Rule/National Pollutant Discharge Elimination System Permitting

FDEP regulates the dairy farms, and other confined animal operations, located in the Lake Okeechobee watershed under State Law, Chapter 62-670.500, F.A.C. (Dairy Rule). The purpose of the rule is to control pollution of waters of the State due to the

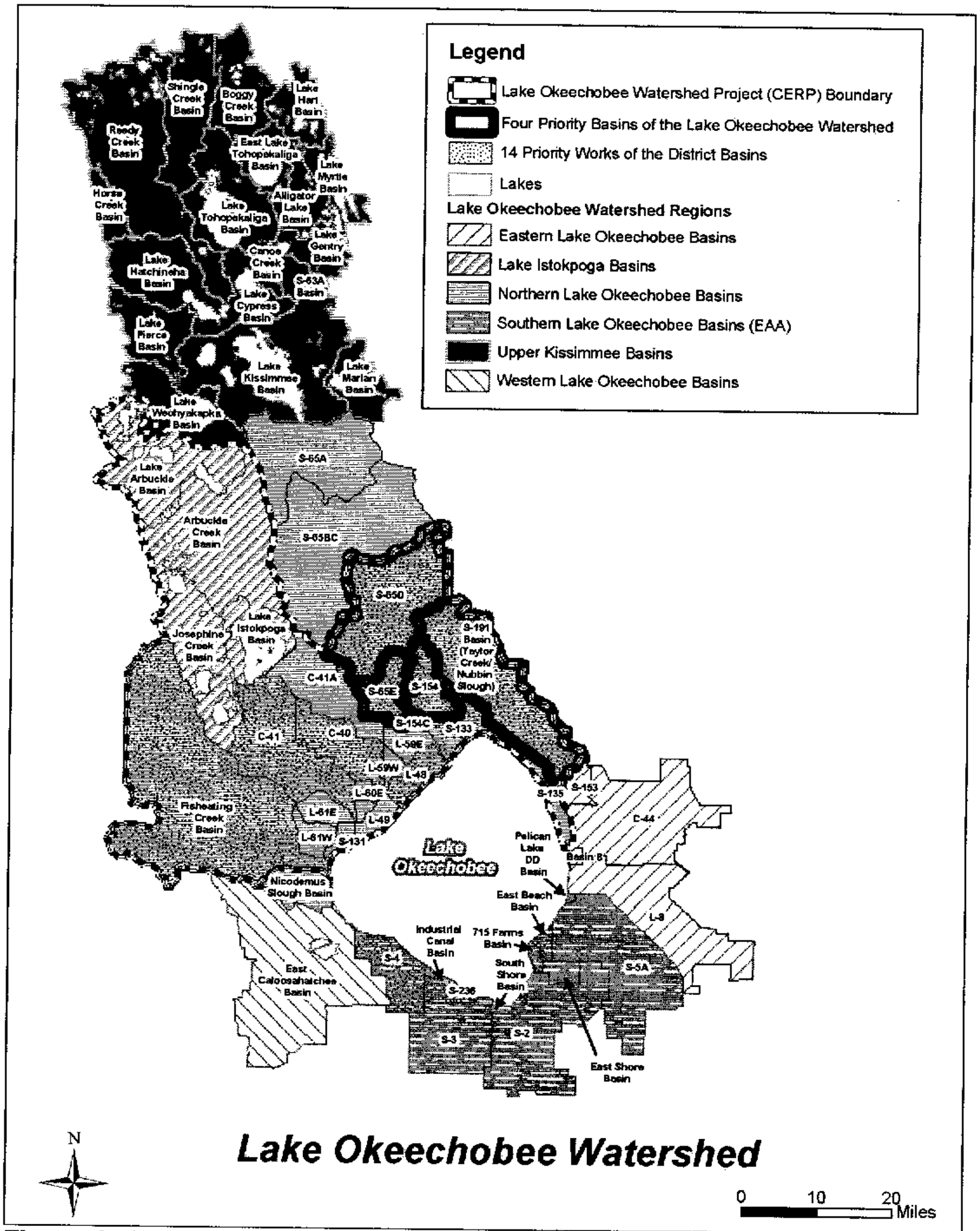

Figure 4. Lake Okeechobee Watershed Basins, Regions, and Priority Basins

discharge of wastewater and runoff from dairies and other confined animal operations in the Lake Okeechobee watershed to surface and groundwater. The system of practices specified in Chapter 62-670.500(5) through (8), F.A.C., for the collection and recycling of wastewater by proper land disposal, together with the associated management practices, is established for the purpose of determining compliance with water quality standards. Implementation of these practices will be presumed to provide reasonable assurance that the facility will meet water quality standards in waters of the State.

Additionally, the United States Environmental Protection Agency (EPA) modified their federal rules regarding National Pollutant Discharge Elimination System (NPDES) permitting of concentrated animal feeding operations (CAFOs). The State must implement these federal rules by April of 2004. Based on EPA's rules, it has been determined that all of the dairies and some of the other CAFOs (horses, hogs, and chickens) located within the Lake Okeechobee watershed must obtain NPDES permits. The permitting requirements include the development and implementation of a nutrient management plan, record keeping, transfer of waste to third parties, and annual reporting. As the current State permits expire, FDEP will be issuing new generic permits that meet the permitting requirements of both the State and NPDES.

Evaluation of Land Use Changes

The LOPA requires that, "Prior to authorizing a discharge into works of the District, the District shall require responsible parties to demonstrate that proposed changes in land use will not result in increased phosphorus loading over that of existing land uses." To meet this requirement, the District is developing a two-tiered approach to help landowners assess the impact of land use changes on phosphorus loads leaving a land parcel. The first-tier approach is the computation of net phosphorus imports from phosphorus budgets for both the current and proposed land uses. If the net import for a proposed land use is less than or equal to the net import for an existing land use without increasing annual runoff volumes, the phosphorus load requirement is considered to have been met. This approach is developed for landowners who do not have a large amount of resources to estimate phosphorus loadings. The methodology is easy to use and can be implemented in a short period of time. If the first-tier approach does not meet the phosphorus load requirements, the second-tier approach requires the use of a computer model to simulate phosphorus loads. Again, if the simulated load for a proposed land use is less than or equal to the simulated load for an existing land use, the LOPA phosphorus requirement is considered to be met. This approach is developed to estimate phosphorus loads using a more rigorous approach than computing net phosphorus imports.

3.1.2 Non-Agricultural Programs

3.1.2.1 Lake Okeechobee Watershed Non-Agricultural Best Management Practice Phosphorus Control Program

A phased approach is being utilized to reduce phosphorus loadings to Lake Okeechobee from non-agricultural areas in the

Lake Okeechobee watershed. The largest contributors of phosphorus loading from non-agricultural areas to Lake Okeechobee are animal feed and fertilizer distributors, golf courses, and failing wastewater systems (septic tanks and package plants). Efforts since the inception of the LOPA include implementation of interim measures (BMPs), master planning for stormwater and wastewater, designs for larger urban stormwater projects, and public education.

The first phase was to implement interim measures. The interim BMPs include those identified in the Florida Land Development Manual, IFAS lawn fertilization rates, and IFAS turfgrass BMPs. These non-structural BMPs primarily target homeowners and businesses. IFAS extension agents are working with homeowners, as well as lawn maintenance companies on better lawn management. The implementation of these BMPs follows a non-regulatory, incentive-based approach.

The next phase is to develop more detailed plans for addressing phosphorus loading to Lake Okeechobee from stormwater and wastewater within the urbanized areas in the watershed. There are currently no central urbanized areas within the four priority basins, so the focus of the non-agricultural program has been outside the four priority basins in those urbanized areas which border Lake Okeechobee. Stormwater master plans are being developed for two of the urbanized areas surrounding Lake Okeechobee: the City of Okeechobee/Okeechobee County and the City of Moore Haven/Glades County, which are anticipated to be complete by March 2004. Additional stormwater master plans will need to be developed for the remaining urbanized areas within the Lake Okeechobee watershed, and will be essential for addressing the stormwater issues in these areas. Because a majority of the urban areas were developed prior to the development of State stormwater regulations, the existing infrastructure is typically inadequate to properly deal with stormwater. Stormwater retrofits, such as detention/ retention facilities, are needed to improve the water quality of the urban stormwater runoff. FDEP is cost-sharing with the City of Okeechobee to improve the water quality of urban stormwater runoff through the installation of a baffle box and the regrading of swales in a residential area near the 4th Street Boat Ramp.

Additionally, wastewater master plans are being completed for these areas to address the need for the upgrading of failing septic tanks and package wastewater treatment plants by connection to the central sewer system, which are anticipated to be complete by January 2004. A part of each plan will address the need to expand the capacity of the central wastewater treatment plant (Okeechobee Utility Authority) to be able to accept the additional wastewater from all of those areas that are currently utilizing failing septic tanks and package wastewater treatment plants.

Public education is an essential component for reducing phosphorus entering the stormwater in the urbanized areas. IFAS, through the Florida Yards and Neighborhoods Program, provides weekly newspaper articles in the Okeechobee newspapers addressing proper lawn maintenance practices. Additionally, a fertilizer brochure has been developed with the fertilizer industry to promote the use of low or no phosphorus fertilizers and the use of appropriate BMPs when utilizing these chemicals. This brochure will be located at retail stores where fertilizers are sold.

3.1.2.2 Phosphorus Source Control Grants

The intent of the Lake Okeechobee Phosphorus Source Control Grant (PSCG) Program is to fund the early implementation of projects that have the potential for reducing phosphorus exports to Lake Okeechobee from the watershed. Currently, the program consists of 13 projects (Figure 3), with a total cost of slightly more than $7 million. FDEP provided funds from the 2002-2003 State General Revenue designated for TMDL implementation projects to add the thirteenth grant project. An Interagency team evaluated the projects and ranked them using established evaluation criteria. The funded projects range in size and complexity, and grant recipients consist of landowners, public facilities, and private corporations.

All PSCG projects have a target implementation date of September 30, 2004, with an operational life of 10 years or more thereafter. As of October 2003, the current status of the 13 projects breaks down as follows: two projects are in the planning/permitting stage, two projects are under construction, six projects are operational and are being monitored, and three projects have been completed. Forecasts for the remainder of calendar year 2003 are that one project will move from the planning to the construction stage, two projects will move from the construction to the operation/monitoring stage, and one project will move from the operation/monitoring stage to the completed status.

Of the 13 PSCG projects, 11 are agricultural. These projects include isolated wetland restoration, stormwater retention areas, chemical treatment of runoff, concrete cooling ponds for dairy cows, and composting of chicken manure.

The two urban PSCG projects are a fertilizer pelletization plant for wastewater treatment residuals from the central east coast of Florida and the replacement of septic systems and package wastewater treatment systems with a gravity sewer system in Okeechobee.

Composting

The Tampa Farm Service (TFS) composting project, funded under the Lake Okeechobee PSCG Program, represents the implementation of a fundamental shift in the disposal approach of chicken wastes from an egg producing company. Currently, TFS collects chicken manure from its Okeechobee and Indiantown complexes and ships it, via truck, to various locations throughout the Lake Okeechobee watershed for land application. The proposed project, to be implemented on the property of the Indiantown complex, calls for the utilization of the collected wastes in a composting process. Chicken manure from both complexes is to be collected and mixed with yard wastes provided by the Martin County landfill and placed into composting windrows. The composting process is envisioned to require approximately five months from the time of initial composting to final curing, with the final material expected to be a stabilized, easy to ship product, which can be used in fertilizer production. This facility, when constructed, will be the only operational composting facility within the Lake Okeechobee watershed.

The chicken wastes have been, and currently are, land applied within the Lake Okeechobee watershed. TFS estimates that 90 percent of the material is currently being applied within the four priority basins (specifically in S-191 and S-65D). This composting is expected to reduce the amount of TFS manure land application and promote its reuse outside of the Lake Okeechobee watershed. It has been estimated that this composting project will reduce phosphorus loading to Lake Okeechobee by approximately 11 Mtons on an average annual basis.

3.1.2.3 Regulatory

Domestic Wastewater Regulations

Generally, FDEP requires entities who intend to collect/transmit, treat, dispose of, and/or reuse domestic wastewater obtain a State and/or federal NPDES wastewater permit. A domestic wastewater permit specifies the construction and operating requirements for the wastewater treatment plant and the associated reuse or disposal systems (effluent, reclaimed water, and residuals). EPA has delegated the authority to issue NPDES permits for domestic wastewater facilities not owned by the federal government to FDEP. Currently, there are 251 domestic wastewater facilities within the Lake Okeechobee watershed. Of the 251 facilities, only 7 facilities are classified as NPDES facilities.

The discharge of wastewater to surface waters cannot cause or contribute to water quality problems, and must be in compliance with any applicable TMDLs for that associated waterbody. More information can be obtained at http://www.dep.state.fl.us/water/wastewater/index.htm.

Another component of the domestic wastewater stream which is regulated under the LOPA is the management of residuals (biosolids) from a wastewater treatment plant. Section 373.4595(3)(6)(a), Florida Statutes, requires all entities disposing of domestic wastewater residuals within the Lake Okeechobee watershed and the remaining areas of Okeechobee, Glades, and Hendry Counties to apply the material at agronomic rates based on phosphorus. By July 1, 2005, phosphorus concentrations originating from these application sites shall not exceed the limits established in the District's WOD program. This requirement has reduced the quantity of material that had historically been land-applied in the watershed. Typically, less material can be applied to a site when it is applied at agronomic rates based on phosphorus as compared to nitrogen. As a result of this, several land application sites chose to discontinue land-applying biosolids. Currently, there are 3 sites north of the Lake and 15 sites south of the Lake which have been approved to receive residuals. The application of septage is also subject to the same requirements, according to Section 373.4595(3)(7), Florida Statutes. The Florida Department of Health permits the application of septage and is responsible for ensuring that the application at these sites is according to phosphorus-based agronomic rates. Currently, there are two sites north of the Lake which are approved to receive septage.

Municipal Separate Storm Sewer System Regulations

NPDES permits are required for many Municipal Separate Storm Sewer Systems (MS4s), which are publicly-owned conveyances that are designed for the discharge of stormwater to surface waters of the State. An NPDES permit is required to protect water quality of surface waters currently receiving discharges from MS4s. As part of a permit, operators of a regulated MS4 must develop a stormwater management program that includes public education and outreach, public participation/involvement, illicit discharge detection and elimination, construction site runoff control, post-construction runoff control, pollution prevention/good housekeeping, and regular reporting. Regulated MS4s are brought under regulation through three mechanisms: automatic designation based on population size, designation by FDEP, and public petition for designation by FDEP. FDEP is currently revising their rules to include the designation criteria for small MS4s. One of the designation criteria for regulation will include any MS4 that discharges to a waterbody with a designated TMDL. More information is available at http://www.dep.state.fl.us/water/stormwater. These designation criteria will require all urbanized areas bordering Lake Okeechobee to be regulated under the NPDES Program. At this time, the date by which these urbanized areas must be under permit has not yet been identified. However, consultants have already worked with the City of Okeechobee/Okeechobee County to complete an NPDES permit application.

3.1.3 Regional Projects / Public-Private Partnerships

The Lake Okeechobee Regional Public-Private Partnership Program solicitation was released on November 15, 2002, and seven proposals were received by the submission deadline. An Interagency selection committee, comprised of representatives from FDEP, FDACS, and the District, evaluated the seven proposals based on evaluation criteria identified in the Program guidelines.

The Governing Board authorized entering into negotiations and subsequent contracts with the two top ranked respondents (Green-Cycle/QED and Davie Dairy) to not exceed a total of $4.75 million. The Green-Cycle (Lake Okeechobee) Inc/QED Environmental Solutions (Florida) LLC project consists of constructing solid separators and wastewater treatment plants at three dairy barns (two at McArthur, and one at H.W. Rucks) and a fertilizer complex to produce an organic fertilizer from the dairy and TFS chicken manure solids. The fertilizer and/or organic soil amendment would be exported from the Lake Okeechobee watershed. The project estimates that 33 Mtons of phosphorus in runoff to the Lake per year would be stopped if the dairies and chicken farms exported their waste in this manner. Green-Cycle will receive $4.2 million from this Program. The proposal also contained an estimate that the private contribution to the project would cost $4.2 million and that the project will generate up to 50 new jobs.

The second ranked respondent, Davie Dairy, is a participant in the District's Dairy BATs project and has completed construction of an edge-of-farm detention area with chemical treatment of farm runoff under that Program. Through the Public-Private Partnership Program, the dairy is proposing to treat an additional 800 acres of off-site runoff through their treatment system, which will provide 0.45 Mtons of phosphorus reduction on an annual basis. Davie Dairy will receive $550,000 to conduct the project. Private contributions were estimated at 24 percent of the total project cost.

Green-Cycle/QED signed a contract in October 2003. Davie Dairy's contract is under development at this time.

Green-Cycle/QED's project schedule estimated that the dairy wastewater treatment plants could be constructed by early next year with the fertilizer plant construction being completed by the end of 2004. Davie Dairy will be capable of treating the off-site runoff by the end of 2003. Both projects are estimated to have a 20-year life, which coincides with the term of the District's contracts.

3.1.4 Research/Studies

3.1.4.1 Lake Istokpoga and the Upper Chain of Lakes

The LOPA specifies that by July 1, 2003, the District will conduct an assessment of the sources of phosphorus from the regions of the Upper Kissimmee Basins and the Lake Istokpoga Basins (Figure 4), and their relative contribution to the water quality of Lake Okeechobee. This task is complete. Two studies were done: the development of a watershed phosphorus budget analysis (Mock Roos, 2003) and an assessment of the sediments in these lakes and their ability to influence phosphorus in the water column (IFAS, 2003).

Watershed Phosphorus Budget Analysis

Phosphorus budgets, estimated from landowner surveys, scientific information, and land use data; a Geographic Information System (GIS); and the Watershed Assessment Model (WAMView) were used to calculate phosphorus imports, exports, retention, and discharge from each basin. These estimates are reported in Mtons of phosphorus per year. Major results are:

- Two percent of the land area changed to residential (the largest change) or to a more intense form of this use from 1995 to 2002.

- **For the Lake Istokpoga Watershed:**
  - The land use change resulted in increased net phosphorus imports (sum of imports-exports) of 1 Mton/yr (less than 1 percent).
  - Net phosphorus imports were 664 Mtons/yr from anthropogenic activities, resulting in 32 Mtons/yr of phosphorus being discharged from the watershed, with the rest remaining in soil, vegetation, and other components of the watershed.
  - Land uses with a high net phosphorus import were: truck crops - 269 Mtons/yr, improved pasture - 246 Mtons/yr, and residential-medium density - 170 Mtons/yr.

- **For the Upper Chain of Lakes Watershed:**
  - The land use change resulted in an increase of net phosphorus imports of 305 Mtons per year (a 9.4 percent increase).
  - Net phosphorus imports were 3,256 Mton/yr from anthropogenic activities, resulting in 35 Mton/yr of phosphorus being discharged out of the watershed, the rest remaining in soil, vegetation, and other components of the watershed.

- Land uses with a high net phosphorus import were: tourist resorts/parks - 1,072 Mton/yr, improved pasture - 805 Mton/yr, and truck crops - 387 Mton/yr.

- **Phosphorus Management Recommendations:**
  - Phosphorus imports should be reduced to the greatest extent possible.
  - Prior to permit approvals, responsible parties should demonstrate that proposed changes in land use will not result in increased phosphorus loading over that of existing land uses.
  - Municipalities should work together with the District to improve the treatment of their stormwater runoff.

Sediment Study

Sediment cores, taken from Lakes Istokpoga, Kissimmee, Hatchineha, Cypress, and Tohopekaliga, were analyzed for chemistry and release and uptake of phosphorus. Major findings were:

- Total phosphorus concentrations in lake sediments indicate that Lakes Tohopekaliga and Istokpoga have been less impacted by phosphorus loading from the surrounding watershed, compared to Lakes Hatchineha, Kissimmee, and Cypress.
- Sediments from both Lake Cypress and Hatchineha do not appear to be contributing significantly to phosphorus discharge from these lakes.
- Sediments from Lakes Istokpoga, Kissimmee and Tohopekaliga may be significant contributors to phosphorus discharge from these lakes.
- The sediments of Lakes Cypress and Hatchineha have little ability to bind with inorganic phosphorus.
- Based on lake area, the total assimilative capacity for Lakes Istokpoga, Kissimmee, Hatchineha, Cypress, and Tohopekaliga were estimated as 653, 600, 330, 133, and 442 Mtons/yr, respectively.

The LOPP proposes implementation of phosphorus reduction activities in the Lake Istokpoga and Upper Kissimmee regions.

3.1.4.2 Phosphorus Budget

Phosphorus-containing materials are transported into and out of the Lake Okeechobee watershed. A portion of the phosphorus imported into the watershed enters the tributaries and is discharged to the Lake, thus contributing to nutrient enrichment of the Lake. Estimating the phosphorus mass balances for each basin in the watershed is the first step toward effective control of phosphorus inputs to the Lake.

The phosphorus budget study entails conducting a phosphorus-containing material budget using a mass balance approach to quantify the net import of phosphorus to the basins in the Lake Okeechobee watershed. The net import of phosphorus is the sum of the phosphorus imports, minus phosphorus exported. The study determined that phosphorus imported into the watershed is primarily in the form of fertilizers (pasture and crop) and dairy feed. The phosphorus exported is primarily in the form of sod, milk, cows, and crops. The average phosphorus import/export coefficients in terms of kg P/ha-yr were estimated using the current land management data for each region in the Lake Okeechobee watershed (Figure 4). The net phosphorus import coefficient for each land use was applied to the corresponding land area to obtain the land use based phosphorus budget. To conduct a watershed-wide phosphorus budget analysis, phosphorus loads in rainfall and runoff were estimated, and the measured phosphorus load to Lake Okeechobee was included.

Land Use Based Phosphorus Budget

The phosphorus budget analysis for the drainage basins located in the regions of the northern Lake Okeechobee basins (Mock Roos Team, 2002), the Upper Kissimmee basins, and Lake Istokpoga basins have been completed (Mock Roos, 2003). Zhang et al. (2003a and 2003b) recently completed the phosphorus budget analysis for the regions of the eastern and southern basins in the Lake Okeechobee watershed (Figure 4). A phosphorus budget analysis for the western (East Caloosahatchee) basin will not be conducted due to the very limited discharge to Lake Okeechobee. The summary results from these studies are listed in Table 2.

Phosphorus Loads in Rainfall

The phosphorus loading rate from rainfall was calculated using the average phosphorus load value from rainfall and the lake area. FDEP estimated through the TMDL process (FDEP, 2001) that 35 Mtons/yr of phosphorus is contributed from rainfall. Lake Okeechobee has a surface area of 173,200 hectares (ha) (Steinman et al., 1999). The annual average phosphorus loading rate was calculated to be (35 Mtons/yr * 1000 kg/t) / 173,200 ha = 0.202 kg P/ha-yr. Based on the total watershed area, the total rainfall phosphorus load to the Lake was estimated to be 269 Mtons/yr.

Table 2. Results of Land Use Based Phosphorus Budget by Region (Metric tons per year used)

Region	Area	P Import	P Export	Net Import
	(ha)	(Mtons/yr)	(Mtons/yr)	(Mtons/yr)
Upper Kissimmee Basins	415,986	3,937	681	3,256
Lake Istokpoga Basins	157,151	1,039	375	664
Northern Lake Okeechobee Basins	515,987	2,961	1,244	1,717
Eastern Lake Okeechobee Basins (C-44, L-8)	96,248	521	182	339
Southern Lake Okeechobee Basins (EAA, 298s)	146,365	3,496	1,908	1,588
Watershed Total	1,331,737	11,954	4,390	7,564

Phosphorus Loads in Runoff

The phosphorus loading rate in terms of kg P/ha-yr and the corresponding land area were used to determine phosphorus runoff load for each land use for the regions of the northern, eastern, and southern Lake Okeechobee basins (Mock Roos Team, 2002; Zhang et al., 2003a and 2003b). The WAMView model (SWET, 2002) was used to compute the phosphorus loads in surface runoff for the other two regions (Mock Roos, 2003). The total amount of phosphorus load in surface runoff was estimated to be 1,054 Mtons/yr.

Phosphorus Loads to Lake Okeechobee

Phosphorus loads from each of the basins to Lake Okeechobee were obtained from data in the 2002 SWIM Plan (SFWMD, 2002). The 2002 SWIM Plan reported the average annual phosphorus loads for the period of 1991 to 2000. On average for this 10-year period, approximately 497 Mtons/yr of phosphorus discharged to the Lake annually from the watershed. Of the 1,054 Mtons/yr (see above) of runoff phosphorus load from the land uses, approximately 557 Mtons/yr of phosphorus was retained by the transport system or discharged to other surrounding basins or waterbodies annually.

Phosphorus Budget Summary

In summary, the total drainage area of the watershed is 13,317 square kilometers. Figure 5 depicts the overall Lake Okeechobee phosphorus budget. Approximately 11,954 Mton/yr of phosphorus was imported into the drainage basins annually from land use activities. About 4,390 Mtons/yr of phosphorus was exported out of the basins, and the net import to these basins was calculated to be 7,564 Mtons/yr of phosphorus (7,833 Mtons/yr including rainfall). The total amounts of phosphorus in rainfall, runoff, and

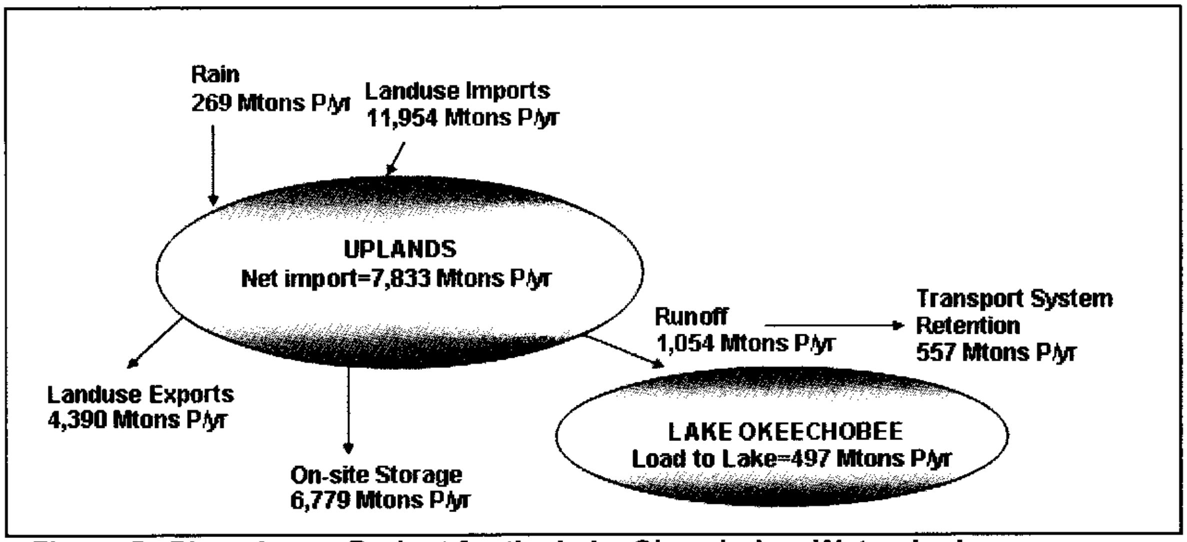

Figure 5. Phosphorus Budget for the Lake Okeechobee Watershed

load to the Lake were 269 Mtons/yr, 1,054 Mtons/yr, and 497 Mtons/yr , respectively. The on-site phosphorus storage, calculated as the sum of total net phosphorus imports (7,833 Mtons/yr) minus phosphorus surface runoff load (1,054 Mtons/yr) was 6,779 Mtons/yr. Approximately 497 Mtons/yr of runoff phosphorus load was discharged to the Lake annually, while 557 Mtons/yr of phosphorus was retained by the transport system.

3.1.4.3 Water Management Practices Assessment

The overall objective of the water management practices assessment project was to assess the benefits of implementing private (urban and agricultural) and District system (tributary) water management practices in the four priority basins of the Lake Okeechobee watershed, with a focus on water retention.

The WAMView watershed assessment model was developed to specifically assess the water quality impacts of land use and land management changes in the Lake Okeechobee watershed. The modeling approach for this project included using WAMView to simulate the benefits of site-level stormwater BMPs and tributary canal stormwater BMPs. Only simple and inexpensive means of water retention were considered for individual properties, including weirs and flashboard risers to retain water in existing ditch systems and low-lying/depressional areas. Crop flooding tolerances were assessed for each land use to ensure that any recommended alternative water management practices would not cause any adverse effects to the production of any agricultural commodity or urban land use.

The evaluation recommended the following retention volumes for each land use as follows, each given in terms of a recommended number of inches of runoff to be retained on a typical site:

- Pastures (1 inch)
- Citrus (0 inches)
- Dairies (1 inch)
- Commercial (0 inches)
- Residential (0 inches)
- Row Crops (0.25 inches)

The overall phosphorus removal attained with these retention volumes per basin varied between 40 and 56 percent, with an average of 52 percent for all four priority basins. Phosphorus loads to Lake Okeechobee from these four basins were reduced in the WAMView model from an average of 186 Mtons per year to 96 Mtons per year, with the simulation of the recommended water management practices on all sites as listed above in the four priority basins.

The tributary canal stormwater retention BMPs were simulated In WAMView and shown to provide additional phosphorus reduction of 2.5 percent. The estimated overall combined tributary and site-level phosphorus reductions total 54.5 percent. This total estimated reduction assumes that the recommended number of inches of runoff retention for each land use, which are stated above, are implemented on all properties. The land use retention volumes are based on amounts of water retention found to be feasible for a typical property of each land use without adversely impacting crops or operations. **This volume will vary for each property in the watershed, and should be site-specifically assessed prior to implementation on individual properties.**

3.1.4.4 Natural Resources Economic Study

Phase I of the recently completed economic analysis study evaluated alternative nutrient reduction technologies, and then conducted a benefit-cost analysis on the selected phosphorus control alternatives (PCAs). A comparison of 12 on-farm and regional PCAs followed using full cost accounting methodology. This study generated a benefit-cost model and related sensitivity studies, and assessed and prioritized the best combinations of regional and on-farm alternative PCAs. The PCAs evaluated included:

- PCA 1- Chemical treatment at edge of field;
- PCA 2- Wetland treatment at edge of field;
- PCA 3- Non-structural management at the land parcel level;
- PCA 4- Optimization of Dairy Rule design;
- PCA 5- Enhanced cow/calf BMPs;
- PCA 6- Alternative land uses;
- PCA 7- Reservoir-assisted stormwater treatment areas (RASTAs);

- PCA 8- Taylor Creek/Nubbin Slough RASTA with supplemental Lake Okeechobee water (later dropped from the analysis);
- PCA 9- Tributary sediment removal;
- PCA 10-Terminal water treatment facility;
- PCA 11- Isolated wetlands restoration; and
- PCA 12- On-farm composting of animal solid waste (later dropped from the analysis).

Full cost accounting attempts were made to identify and quantify all benefits and costs resulting from a policy decision, including social and environmental costs and benefits and cost analysis to third parties. Natural resources valuation principles were utilized, and included the determination of the economic impacts to the surrounding communities that each of the strategies could present.

A Computerized Alternatives Evaluation/Full Cost Accounting Model was developed as part of this study. A ranking of initial alternatives was developed, based on the magnitude of itemized benefits and costs, using the Criteria DecisionPlus® software. The computerized model allows the evaluation of additional PCAs, as updated information becomes available. Initially, the PCAs were evaluated with respect to 10 evaluation criteria, and PCA 5-Enhanced Cow/Calf BMPs, was ranked the highest. The Evaluation Criteria included (A) Phosphorus Reduction Benefits, (B) Cost-Effectiveness, (C) External Benefits and Costs, and (D) Risk and Uncertainty Measures. Table 3 provides the complete ranking of the individual PCAs that were evaluated, as well as the results of three phosphorus reduction benefits criteria.

As a result of the desktop evaluation summarized below, Phase II of the study evaluated 18 PCA combinations that included three regional technologies and six on-farm technologies that would be considered for implementation in the Lake Okeechobee study area under the Lake Okeechobee Natural Resources Economic Study. The evaluation of combinations in the second phase of this study was prompted by improved project information being generated, and the assumption that a combination of both on-farm and regional alternatives is needed to reduce the phosphorus loads in the watershed.

The combinations evaluation used the same Full Cost Accounting Model and the Criterium DecisionPlus® Model that was used in the ranking of the individual PCAs. The impact of on-farm PCA effluent phosphorus loads on the input phosphorus concentrations of the regional PCAs was estimated and used in the final analysis of combinations. The ranking and results of the three main phosphorus based criteria for the 18 PCA combinations are contained in Table 4. The combination of RASTAs with Dairy

Table 3. Evaluation of Phosphorus Control Alternatives

Rank	Individual PCA/ Location	Criterion 1: P Removed per Year (pounds)	Criterion 2: Resulting P Concentration (ppb)	Criterion 3: Present Value Cost per Pound P removed ($)
1	Cow/calf BMPs / on-farm (PCA 5)	197,000	208	$49
2	RASTAs / regional (PCA 7)	94,000	40	$104
3	Taylor Creek/Nubbin Slough RASTA with supplemental LO water / regional (PCA 8)	72,000	40	$90
4	Non-structural management at the land parcel level / on-farm (PCA 3)	270,000	221	$50
5	Terminal Water Treatment Facility / regional (PCA 10)	119,000	10	$139
6	Wetland Treatment at edge of field / on-farm (PCA 2)	148,000	297	$127
7	Alternative land uses / on-farm (PCA 6)	74,000	337	$268
8	Chemical treatment at edge of field / on-farm (PCA 1)	216,000	123	$184
9	Tributary sediment removal / regional (PCA 9)	29,000	212	$6
10	Optimization of Dairy Rule design / on-farm (PCA 4)	19,000	750	$108
11	Isolated Wetland Restoration (100,000 acres) (PCA 11)	61,000	193	$109

Table 4. Summary of Evaluation Results – PCA Combinations					
Rank	PCA Combination	Criterion 1: P Removed per Year (pounds)	Criterion 2: Resulting P Concentration (ppb)	Criterion 3: Present Value Cost / lb P removed ($)	% of Controllable Load to Lake Removed (545,076 lbs/year)
RASTAS					
1	Combination 2: PCAs 7, 4 and 5 – RASTAs with Dairy Farm Optimization and Enhanced Cow/Calf BMPs	301,242	40	$54	55%
2	Combination 5: PCAs 7 and 3 – RASTAs with Non-Structural Management at the Land Parcel Level	327,788	40	$68	60%
5	Combination 1: PCAs 7 and 11 – RASTAs w/ Isolated Wetlands Restoration on Pastureland	188,078	40	$121	35%
7	Combination 4: PCAs 7 and 2 – RASTAs with Wetlands Treatment of Runoff at Edge of Property	232,516	40	$121	43%
8	Combination 3: PCAs 7 and 1 – RASTAs with Chemical Treatment of Runoff at Edge of Property	295,426	40	$134	54%
11	Combination 6: PCAs 7 and 6 – RASTAs with Alternative Land Uses	159,312	40	$181	29%
TERMINAL LARGE SCALE WATER TREATMENT FACILITY					
3	Combination 8: PCAs 10, 4 and 5 – Terminal Large Scale Water Treatment Facility with Dairy Farm Optimization and Enhanced Cow/Calf BMPs	319,592	10	$103	59%

Table 4. Summary of Evaluation Results – PCA Combinations					
Rank	PCA Combination	Criterion 1: P Removed per Year (pounds)	Criterion 2: Resulting P Concentration (ppb)	Criterion 3: Present Value Cost / lb P removed ($)	% of Controllable Load to Lake Removed (545,076 lbs/year)
6	Combination 11: PCAs 10 and 3 – Terminal Large Scale Water Treatment Facility with Non-Structural Management at the Land Parcel Level	345,732	10	$83	63%
10	Combination 7: PCAs 10 and 11 – Terminal Large Scale Water Treatment Facility with Isolated Wetlands Restoration on Pastureland	211,550	10	$139	39%
13	Combination 10: PCAs 10 and 2 – Terminal Large Scale Water Treatment Facility with Wetlands Treatment of Runoff at Edge of Property	253,053	10	$136	46%
16	Combination 9: PCAs 10 and 1 – Terminal Large Scale Water Treatment Facility with Chemical Treatment of Runoff at Edge of Property	313,993	10	$177	58%
17	Combination 12: PCAs 10 and 6 – Terminal Large Scale Water Treatment Facility with Alternative Land Uses	182,186	10	$196	33%
TRIBUTARY SEDIMENT REMOVAL					
4	Combination 14: PCAs 9, 4 and 5 – Tributary Sediment Removal with Dairy Farm Optimization and Enhanced Cow/Calf BMPs	261,258	233	$58	48%

Table 4. Summary of Evaluation Results – PCA Combinations					
Rank	PCA Combination	Criterion 1: P Removed per Year (pounds)	Criterion 2: Resulting P Concentration (ppb)	Criterion 3: Present Value Cost / lb P removed ($)	% of Controllable Load to Lake Removed (545,076 lbs/year)
9	Combination 17: PCAs 9 and 3 – Tributary Sediment Removal with Non-Structural Management at the Land Parcel Level	289,473	216	$46	53%
12	Combination 13: PCAs 9 and 11 – Tributary Sediment Removal with Isolated Wetlands Restoration on Pastureland	149,710	193	$72	27%
14	Combination 16: PCAs 9 and 2 – Tributary Sediment Removal with Wetlands Treatment of Runoff at Edge of Property	183,544	306	$103	34%
15	Combination 15: PCAs 9 and 1 – Tributary Sediment Removal with Chemical Treatment of Runoff at Edge of Property	254,545	125	$157	47%
18	Combination 18: PCAs 9 and 6 – Tributary Sediment Removal w/ Alternative Land Uses	100,738	501	$194	18%

Rule optimization and enhanced cow/calf BMPs were ranked first 100 percent of the time (basin-specific combinations may be forthcoming).

3.1.4.5 Alternative Nutrient Reduction Technologies

The Desktop Evaluation of Alternative Nutrient Reduction Technologies was also conducted during the second phase of the Lake Okeechobee Natural Resources Economic Study (described above), to comply with the Lake Okeechobee Protection Program requirement that the feasibility of alternative nutrient reduction technologies be evaluated, which included sediment traps, canal and ditch maintenance, fish production or other aquaculture, bio-energy conversion processes, and algal or other biological treatment technologies. The evaluation identified and screened various alternative nutrient reduction technologies using the Phase I benefit-cost evaluation model developed for the Lake Okeechobee Natural Resources Economics Study. The desktop evaluation utilized a literature search, and the benefit-cost analysis model used for the original Phosphorus Control Alternatives (PCAs), to identify and screen potential alternative nutrient reduction technologies.

The screening criteria used to determine if an alternative nutrient reduction technology would be considered for evaluation included:

1. Sufficient information;
2. Phosphorus reduction potential;
3. Confidence of sustained performance;
4. Timeliness; and
5. No significant negative side effects.

In order for the technology to be considered for inclusion in the benefit-cost evaluation of PCAs, the technology had to pass all the screening criteria. Table 5 lists the alternative nutrient reduction technologies screened during the desktop evaluation in two categories, regional and on-farm.

Table 5. List of Alternate Nutrient Reduction Technologies Screened During the Desktop Evaluation of Lake Okeechobee Alternate Nutrient Reduction Technologies

Regional Technologies
1. Regional Processing of Sewage Sludge and/or Animal Solid Waste Residuals
2. Aquaculture and/or Algal-Based Water Treatment Systems
3. Reservoir-Assisted Stormwater Treatment Areas (RASTAs) *
4. Terminal Large Scale Water Treatment Facility Using Chemical Treatment and Solids Separation (CTSS) *
5. Canal and Tributary Maintenance Program *
6. Tributary Sediment Traps
7. Modify Design and Operation of Regional Water Control Structures
On-Farm Technologies
8. Isolated Wetlands Restoration*
9. Improved Dairy Farm Waste Processing Technologies*
10. Stormwater Retention, Reuse and Chemical Treatment at Edge of Properties *
11. Wetlands Treatment of Runoff at Edge of Properties *
12. Non-Structural Management at the Land Parcel Level *
13. Enhanced Cow/Calf Best Management Practices *
14. Alternative Land Uses *
15. Phosphorus Absorption, Binding, and Filtration Technologies
16. Additional Farm Level Best Management Practices
17. On-Farm Composting of Animal Solid Waste *
* PCAs that passed all the screening criteria and were evaluated in Phase II.

As a result of the Desktop Evaluation, 18 PCA combinations were evaluated that included three regional and six on-farm technologies that would possibly be considered for implementation in the Lake Okeechobee watershed. The results are summarized in Section 3.1.4.4.

3.1.5 Effectiveness

3.1.5.1 Best Management Practices

According to the LOPA, a two-phased approach will be used to determine the effectiveness of BMPs. The first phase requires that FDEP use best professional judgment in making the initial determination of BMP effectiveness. An Interagency team worked with outside experts in this field on developing the initial BMP performance estimates for all land uses. This level of verification provided the necessary confidence to the coordinating agencies to immediately move forward in implementing BMPs, even if extensive data on their effectiveness was not available. Implementation of BMPs from adopted and approved BMP manuals, based on an FDACS farm assessment or a site-specific plan developed through NRCS, would qualify for this phase.

The second phase involves the District or FDEP conducting water quality monitoring at representative sites to verify the effectiveness of BMPs. Monitoring during this phase will be conducted at a basin and sub-basin scale by the District through the WOD Program, and at the parcel level through IFAS research demonstration projects designed to verify the effectiveness of a typical suite of BMPs. The data generated from these studies will provide model input (i.e. EAAMOD) to support information already being used by the coordinating agencies to assess overall BMP performance for the watershed. Current projects include:

- Demonstration of Water Quality Best Management Practices for Beef Cattle Ranching in the Lake Okeechobee Basin (IFAS);
- Phosphorus Retention and Storage by Isolated and Constructed Wetlands in the Okeechobee Drainage Basin (IFAS);
- Crop Phytoremediation of Phosphorus-Enriched Soils in the Lake Okeechobee Region (IFAS); and
- Cattle BMP Optimization at Buck Island Ranch (Archbold Expedition).

This basin and sub-basin monitoring will be conducted through the Lake Okeechobee Watershed Project (LOWP) of the Comprehensive Everglades Restoration Plan (CERP) and through the District's ambient water quality monitoring program. Through the LOWP, the United States Geological Survey will be monitoring

17 sub-basin sites within the LOWP boundary (Figure 4) north of Lake Okeechobee. More information is available at http://www.evergladesplan.org/pm/projects/pdp_01_lake_o_watershed.cfm.

In addition, the District also has restructured the WOD farm level monitoring network to a micro-basin level monitoring network for ten basins discharging into Lake Okeechobee from the watershed. These basin, sub-basin, and micro-basin sampling sites will be used to monitor changes in water quality (phosphorus loads and concentrations). If changes are observed, the District has the ability to do more intensive monitoring within the basin to identify the sources of phosphorus. If high phosphorus source areas are detected, the coordinating agencies can require the implementation of additional BMPs.

3.1.5.2 Project Effectiveness

Implementation and demonstration projects funded under the LOPA include phosphorus load monitoring to determine the ability of projects or practices to reduce phosphorus loads to Lake Okeechobee. This information will be utilized in determining the appropriate management strategies needed to achieve the overall desired phosphorus load reductions.

3.1.5.3 Program Effectiveness

The overall effectiveness of the Lake Okeechobee Protection Program will be determined through the monitoring of phosphorus loads entering Lake Okeechobee. The total cumulative phosphorus loading from the watershed allowed by the TMDL is 105 Mtons/yr. The data utilized in this determination is collected by the District at the structures entering Lake Okeechobee.

3.2 Exotic Species Control Program

The objective of the LOPA Exotic Species Control Program is to identify the species (both exotic and nuisance) that threaten the native flora and fauna within the Lake Okeechobee watershed and develop and implement measures to protect the native species. In June of 2002, the mandated LOPA Exotic Species Plan was completed and is included as Appendix 1. The LOPA Exotic Species Plan can also be found at http://www.sfwmd.gov/org/wrp/wrp_okee/projects/exotic_species.pdf. The goal of the exotic species program is to reach maintenance control on the priority species listed in the Plan, as well as other species which may become invasive in the future.

The in-lake treatment targets are:

1.) *Reduce torpedograss (Panicum repens) populations in the littoral zone in Lake Okeechobee.* Since 2000, more than 8,000 acres of torpedograss have been treated in Lake Okeechobee's marsh, with 4,000 acres of torpedograss treated in 2002. Most treatments occurred in or near the Moore Haven marsh in areas where torpedograss was threatening or had already invaded native spikerush/open water habitat.

2.) *Eradicate melaleuca (Melaleuca quinquenervia) from the littoral zone in Lake Okeechobee.* The treatment of existing mature trees was completed. Additional management activities were initiated including removing and/or treating seedlings and other young melaleuca trees before they mature and produce seed.

3.) *Reduce Brazilian pepper (Schinus terebinthifolius) populations in the littoral zone, including spoil bank areas in Lake Okeechobee.* The treatment of most mature trees was completed in 2002. Monitoring for signs of re-growth will continue throughout the marsh, with additional treatments as needed.

4.) *Establish desirable native plant communities in areas now dominated by exotic plants.* Large-scale natural recruitment of native plants has been observed in many treatment areas previously dominated by torpedograss. Plant management activities designed to reduce the area coverage and density of exotic vegetation and promote the re-establishment of native plants will continue. Management efforts will interface with other local and state programs.

Exotic vegetation will be treated according to species-specific management plans. Monitoring continues throughout the year to evaluate treatment efficacy of all species. Vegetation maps are produced using GIS to evaluate treatment efficacy, the rate of recovery of native vegetation in areas where torpedograss has been treated, and the rate of torpedograss expansion in untreated areas.

3.3 Internal Phosphorus Management Program

The Lake Okeechobee Protection Program requires that "by July 1, 2003, the District, in cooperation with the other coordinating agencies and interested parties, shall complete a Lake Okeechobee internal phosphorus load removal feasibility study. The feasibility study shall be based on technical feasibility, as well as economic considerations, and address all reasonable methods of phosphorus removal. If methods are found to be feasible, the District shall immediately pursue the design, funding, and permitting for implementing such methods" (Section 373.4595(3)(f), Florida Statues).

3.3.1 Sediment Management Feasibility Study

In April 2003, the Lake Okeechobee Sediment Management Feasibility Study was completed (BBL, 2003). This was a three-year scientific and engineering evaluation of management options designed to address elevated levels of phosphorus in the mud sediments of Lake

Okeechobee, which act as a source of internal phosphorus load to the water column.

The 36 potential sediment management options with the potential to address internal loading were initially screened on the basis of effectiveness, implementability, risk, reliability, and applicability to Lake Okeechobee. Following the screening process, the alternatives listed below were retained for full-scale evaluation:

- No In-Lake Action;
- Chemical Treatment Using Aluminum Sulfate (alum) and Sodium Aluminate; and
- Dredging.

Each alternative was evaluated against 26 clearly defined performance measures related to the five primary project goals. The evaluation incorporated water quality modeling results, along with engineering evaluations, detailed cost estimates, interviews, case study reviews, socioeconomic analyses, and public and Interagency input. All analyses were based on the assumption that external phosphorus loads would be reduced to the TMDL of 140 Mtons by 2015.

The results of the feasibility study indicated that the No In-Lake Action scenario would be the best scenario. Analysis of the No In-Lake Action scenario indicated a decrease in the annual frequency of algal blooms to below a 15 percent annual probability of a bloom occurrence (from a current annual likelihood of approximately 20 percent) by 2015 and a decrease to below 10 percent by 2028. Steady-state lake recovery conditions would be achieved approximately 35 years from the point that external loads are reduced to the inflow load of 140 Mtons (BBL, 2003). Additional details may be found by downloading the April 2003 final report from http://www.sfwmd.gov/org/wrp/wrp_okee/projects/sediment management.html.

3.3.2 Sediment Removal Pilot Project

The Lake Okeechobee Pilot Dredging Project was completed in December 2002 (EA, 2002). The primary objective of the pilot dredging project was to demonstrate the effectiveness of an innovative sediment dredging technology (the SEDCUT technology) in removing the phosphorus laden mud sediment layer from the bottom of Lake Okeechobee, with a minimal contribution to turbidity in the in-lake water column. The results from this demonstration project were incorporated into the Sediment Management Feasibility Study (BBL, 2003).

The Lake Okeechobee Pilot Dredging Report (EA, 2002) describes activities undertaken during the project's implementation. It summarizes the results and observations from pilot dredging activities conducted in Lake Okeechobee during May 2002. The final report is available at http://www.sfwmd.gov/org/wrp/wrp_okee/projects/pilotdredging.html.

Key results of the demonstration project are listed below:

- Under specific conditions, the technology was capable of reducing the water content in the sediment slurry.
- Review of the water quality data indicated no significant increases compared to background concentrations.
- The technology can be scaled up for use in the larger areas of the Lake where the sediments are known to be concentrated.
- A series of bathymetric (bottom sediments) surveys conducted prior to, during, and after dredging indicated that some relatively heavy shoaling had occurred since dredging was completed. In the course of execution of any larger lake project, the constant shifting of the soft sediments could have a significant impact on dredging operations. Consequently, areas dredged may not be 100 percent cleaned of any soft sediment.
- Lake sediments contained arsenic concentrations that would require special disposal consideration during full-scale dredging of the Lake.

3.3.3 Other In-Lake Restoration Activities

The restoration of valuable habitat within Lake Okeechobee for fish and wildlife and for establishment of native plant/animal communities can help to increase the Lake's ability to assimilate phosphorus. Previous efforts during the drought of 2000 and 2001 concentrated on the removal of organic material that accumulated along the northwest lakeshore in the late 1990's due to high water levels. Recent efforts are focusing on the restoration of Torry and Kreamer Islands at the south end of the Lake through the removal of earthen berms to facilitate water flow between the Lake and the interior of the islands, as well as native vegetation replanting on Torry Island.

Three cooperatively funded navigational sediment removal projects are being conducted with three local municipalities along the southern shore of Lake Okeechobee. Over the past few years, and for various reasons, sediments have filled the Pahokee Harbor, the Belle Glade Marina, and the Industrial Canal in Clewiston. Funds appropriated in Fiscal Year 2001 were used toward removing the sediments that have accumulated in these areas. These projects will reduce the amount of phosphorus-laden sediments that could potentially be redeposited into Lake Okeechobee or transported downstream to the Everglades system. Since the Pahokee Harbor is located within the Herbert Hoover Dike, this project will also be reducing the amount of phosphorus-laden sediments in Lake Okeechobee. The only material proposed for removal is that which is necessary to achieve the original design capacity and cross-section of the marinas and waterway. The Industrial Canal, Belle Glade Marina, and Pahokee Harbor sediment removal projects have been completed.

3.4 Phase I Lake Okeechobee Construction Project

Phase I of the Lake Okeechobee Construction Project is intended to cause immediate phosphorus load reductions to Lake Okeechobee, consistent with the recommendations of the South Florida Ecosystem Restoration Working Group's Lake Okeechobee Action Plan. The status and performance of the projects that comprise Phase I are described below.

3.4.1 Lake Okeechobee Water Retention/Phosphorus Removal Critical Project

3.4.1.1 Stormwater Treatment Areas

Plans and specifications were completed for the Taylor Creek (Grassy Island Ranch) Stormwater Treatment Area (STA) in December 2002 and for the Nubbin Slough (New Palm/Newcomer Dairy) STA in June 2003. Construction is expected to be completed by September 2004 for Taylor Creek and by September 2005 for Nubbin Slough.

The reduction of phosphorus loads to Lake Okeechobee is expected to be 0.85 Mtons of phosphorus per year for the Taylor Creek STA and 2.02 Mtons of phosphorus per year for the Nubbin Slough STA. These estimates are based on simulations using the steady-state STA model, using lower inflow concentrations after BMPs are implemented and accounting for assimilation in tributaries.

3.4.1.2 Isolated Wetlands

The Byrd Isolated Wetland Critical Project was completed in June 2002. Two other sites being designed were suspended because the landowners were unable to continue participating. The remaining sites were suspended due to lack of funding in the Critical Projects Program.

The monitoring of phosphorus concentrations is conducted at the inflows and at the outflow. The storage of the first inch of runoff resulted in only two discharge events since the completion of construction, which demonstrates a significant reduction in phosphorus loads from this site.

3.4.2 Lake Okeechobee Tributary Sediment Removal Pilot Project

The Tributary Sediment Removal Pilot Project is testing a continuous deflective separation (CDS) unit and a tributary sediment trap (TST) for a small portion of the flow in Lettuce Creek. Monitoring began in October 2002 and will continue through September 2003. Water quality, flow, and sediment data will be used to calculate the phosphorus removal efficiency of the CDS and TST. Total cost including operation and maintenance fees and cost per unit of phosphorus removed will be analyzed for each technology to determine if one or both technologies are technically and economically effective methods of reducing phosphorus loads to Lake Okeechobee.

The performance of both systems for phosphorus removal will be assessed in a final report after the monitoring period ends. However, the first six months of monitoring suggest that the sediments in the water column are too fine to settle in the CDS or TST. Therefore, preliminary results show very little phosphorus load reductions. Experiments are underway to evaluate the feasibility of enhancing the phosphorus removal efficiency of the devices by chemical addition.

3.4.3 Taylor Creek/Nubbin Slough Reservoir Assisted Stormwater Treatment Area

The Taylor Creek/Nubbin Slough RASTA is one of four components of the LOWP. The LOWP is currently in the Plan Formulation stage. A RASTA is the primary type of management measure being considered to address the storage and load reduction objectives of the project. Alternative technologies are also being evaluated. Management measures have been identified and preliminary alternatives are being developed. It is anticipated that the tentatively selected plan will be completed by January 2005.

The LOWP, including the Taylor Creek/Nubbin Slough RASTA, will be a major component of Phase II of the Lake Okeechobee Construction Project. The goal of the LOWP for reducing phosphorus loads to Lake Okeechobee will be consistent with the LOPP. The LOPP will provide the target for the reduction of phosphorus load to be achieved by the LOWP.

3.5 Monitoring of Lake Water Quality and Ecological Conditions

3.5.1 Assessment of Water Quality and Ecological Conditions, and Research related to Lake Restoration

The LOPA specifies that the District, in cooperation with other coordinating agencies, will establish a Lake Okeechobee Research and Water Quality Monitoring Program that will accomplish the following:

1. *Evaluate all available existing water quality data concerning total phosphorus in the Lake and its watershed, in order to develop a baseline for total phosphorus.*

   Detailed results for spatial and temporal variation of in-lake total phosphorus are presented in Appendix 2. Results for the watershed phosphorus baseline are presented in Appendix 3. In regards to the phosphorus levels in Lake Okeechobee, they continue to average more than 120 ppb total phosphorus, and indicate that the ecosystem is in a highly eutrophic condition. There have been some increases in lake water phosphorus concentrations in recent years and what appears to be a continued decline in the Lake's ability to assimilate incoming phosphorus from the watershed. The Lake's poor capacity to assimilate phosphorus is a major reason why a relatively low TMDL is required to protect the ecosystem.

2. *Monitor long-term ecological changes, including water quality, measure compliance with water quality standards for total phosphorus, and implement total phosphorus monitoring at all inflow structures.*

The District has maintained a program of routine water quality monitoring on Lake Okeechobee and its inflow structures since the early 1970's. The data collected in this program are available to the general public using a graphical user interface on the District's website. This water quality monitoring program will continue to provide the necessary information to support the LOPP, including information regarding how the LOPP is reducing phosphorus loads to Lake Okeechobee and how water quality in the Lake is responding to those load reductions.

The LOPP also includes a comprehensive program to track changes in the Lake's biological communities that are expected to result from improved water quality and hydrology. A detailed description of this monitoring program, including maps of sampling locations, methods for sample collection and processing, and quality control procedures, is provided in the "Lake Okeechobee Restoration Assessment Plan" (Appendix 4).

The biological assessment program has collected approximately five years of baseline data for most of the key attributes needed to assess ecosystem health. Attributes being evaluated range from submerged plant communities to the occurrence of bloom-forming algae in the lake water. The Restoration Assessment Plan will measure the set of water quality, biological, and hydrologic "performance measures" (quantitative indicators of ecosystem health with specified recovery targets). These performance measures reflect our expectation that a substantial reduction in phosphorus loading to the Lake will result in reduced phosphorus concentrations in the water, changes in nutrient ratios that will make dominance by bloom-forming blue-green algae decline, and improve the underwater light conditions for growth of native submerged plants. These changes, in turn, will create conditions better suited for development of a healthy balanced community of fish and other fauna in the ecosystem. More favorable water levels in the Lake, largely driven by CERP projects, and removal of exotic species (an ongoing Interagency effort) are expected to have synergistic positive effects with the phosphorus reduction programs.

The majority of water quality, biological and hydrologic assessment efforts carried out during implementation of the LOPP will be done by the District, and the resulting data will be maintained in a centralized Lake Okeechobee Database, which already has been developed for this purpose. Certain components of the biological monitoring, in particular the fisheries and macro-invertebrate communities, will continue to be assessed in a long-term program carried out by the Florida Fish and Wildlife Conservation Commission, with funding from CERP.

The Restoration Assessment Plan (Appendix 4) also describes priority research projects that are either underway at this time, or are proposed for the next five years. These projects are aimed at reducing uncertainty about certain lake responses to reductions in phosphorus loads and changes in water level, and will provide important guiding information during the implementation of LOPP and CERP projects. The results of this research will also strengthen the information base that is used in the five-year reevaluation of the Lake Okeechobee phosphorus TMDL.

3.5.2 In-Lake Modeling

The LOPA specifies that, by July 1, 2003, the District will develop a Lake Okeechobee water quality model that reasonably represents phosphorus dynamics of the Lake and incorporates an uncertainty analysis associated with model predictions.

Two water quality models have been developed for Lake Okeechobee:

1) **The Lake Okeechobee Water Quality Model** (LOWQM), which treats the Lake as one water column box, a surface sediment layer and deep sediment layer, and
2) **The Lake Okeechobee Environment Model** (LOEM), which is a three dimensional hydrodynamic and water quality model.

The LOWQM is being used for long-term (30 to 100-year) predictions to determine the impact of various nutrient load reduction strategies and to assist the Initial Comprehensive Everglades Restoration Plan Update. A rigorous uncertainty analysis of the LOWQM also has been conducted. This analysis helped determine the certainty of model predictions and helped define where further research is needed to improve model predictions.

The LOEM is being developed to include water column water quality, sediment water quality and submerged aquatic vegetation (SAV). This model will be fully tested and operational by 2004. It will be used to assist the development of management strategies to improve the SAV in the Lake. One major benefit of this model is the ability to predict changes in water quality in certain critical regions of the Lake (e.g. the shoreline areas). That cannot be done with the single water column box used in the LOWQM.

3.6 Monitoring of Watershed Water Quality

The District operates and maintains an extensive water quality monitoring program for Lake Okeechobee and its drainage basins. There are three levels of monitoring that is being conducted in the watershed: basin, sub-basin/tributary, and micro-basin scale. In the past, under the WOD Program, monitoring was also conducted at the farm-scale level. Basin monitoring of inflows at District operated control structures has been ongoing since 1973. Sub-basin monitoring of tributaries in the S-191 (Taylor Creek/Nubbin Slough) basin began in 1977 and was further expanded to tributaries in S-65E, S-65D, and S-154 basins in 1987. Farm-scale monitoring through the WOD and Dairy Rule regulatory programs began in 1989. During the past year, the WOD Program monitoring network was restructured to monitor at the micro-basin level. This allowed the District to redirect its limited resources to cover a larger portion of the watershed. Information from basin-level monitoring includes flow and concentration to calculate nutrient loads. Monitoring at the sub-basin, micro-basin, and farm-scale level is limited to nutrient concentrations.

The basin monitoring program provides information to calculate nutrient loads discharging to Lake Okeechobee, and to determine if such discharges are in compliance with water quality standards. Some of the monitoring stations are currently regulated by FDEP through the Lake Okeechobee Operating Permit. The tributary monitoring program provides nutrient concentration, chemical, and physical data for the evaluation of trends. The computation of nutrient loads and flow-weighted concentrations is not performed for this level of monitoring. Data from the micro-basin level monitoring, which began in the fall of 2003, will be used to provide information to FDACS, so that they can appropriately direct their resources. Areas with high phosphorus concentrations are a priority. Historically, the farm-scale monitoring was limited to strictly nutrient concentrations, which were measured to determine if the average non-point source discharges were meeting target total phosphorus concentrations established in Technical Publication 81-2 and memorialized in the SWIM Plan.

In addition to the accomplishments outlined above, which were initiated to meet future year statutory requirements in the law, the coordinating agencies have met all the specific Calendar Year 200 requirement deadlines.

4.0 Challenges/Unresolved Issues/Major Uncertainties

- Funds for monitoring phosphorus reductions by non-agricultural BMPs
- Amending the Works of the District Rule to better interface with LOPP projects including the FDACS BMP Rule and adopting non-agricultural BMPs into the WOD program.

5.0 Encumbrances / Expenditures for Fiscal Years 2001, 2002, and 2003

Table 6 indicates the distribution of funding, encumbrances, and expenditures for the State-appropriated funds from Fiscal Years 2001, 2002, and 2003. Although indicating a slow start in the expenditure of funds, significant progress has been made with many of the programs as indicated in the Program Management Plan.

Table 6. Fiscal Year 2001, 2002, and 2003 State Funding Appropriations, Encumbrances, and Expenditures for the Lake Okeechobee Protection Program

FDACS - FY01 One-time appropriation, 1591-G, 2000-01 GAA $15,000,000	Appropriation	Contract Agreement Executed / Encumbered	Expended	Balance	Comments
Salaries, Overhead and Travel			$ 1,035,120		$450,000 needed annually to support administration of Lake O. Protection Program
Operating Capital Outlay			$ 125,110		
Motor Vehicles			$ 59,904		
Administrative Overhead Transfer			$ 92,854		
Certified Forward Encumbered Funds			$ 336,235		
NRCS contract			$ 189,107		
Dairy Nutrient Management Assessments & Implementation		$ 166,843	$ 1,746,358		Engineering design and cost-share to implement dairy nutrient management plans
Nutrient management planning for cow/calf operations		$ 1,134,594	$ 902,822		Nutrient management planning and cost-share for cow / calf operations
IFAS education, research, and demonstration project		$ 1,176,936	$ 268,604		Research and demonstration for BMP development; Total contract amount remains $2,010,384
Phosphorus Removal		$ 302,335	$ 245,965		Hydromentia / P-sensor project
TOTAL FOR FDACS	**$ 15,000,000**	**$ 2,780,708**	**$ 5,002,079**	**$ 7,217,213**	

SFWMD - FY01 Appropriation $23,500,000	Appropriation	Contract Agreement Executed / Encumbered	Expended	Balance	Comments
3 Year Leased Position - Project Manager	$ 205,505		$ 122,901	$ 82,604	Planned to be expended by May 2005
Training	$ 2,000	$ -	$ 718	$ 1,282	Training for new leased employees
Berryman & Henigar - Engineering Oversight Contract	$ 300,000	$ 149,164	$ 150,836	$ -	
LO Torpedograss Management	$ 500,000	$ -	$ 499,519	$ 481	
Davie Dairy, Inc.	$ 95,270	$ 700	$ 94,570	$ -	
Smith Okeechobee Farms, Inc.	$ 409,560	$ 300,176	$ 109,384	$ -	
Evans Properties, Inc.	$ 157,000	$ -	$ 157,000	$ -	
Okeechobee Utility Authority, Ousley	$ 506,000	$ -	$ 506,000	$ -	
Tampa Farm Service	$ 1,300,810	$ 919,587	$ 381,223	$ -	
Irene Lofton	$ 92,000	$ 12,640	$ 79,360	$ -	
Aquaflorida, Inc.	$ 516,600	$ -	$ 516,000	$ 600	
SWA of PBC	$ 1,125,000	$ 1,125,000	$ -	$ -	
Daniel & Marcia Candler	$ 120,000	$ 30,000	$ 90,000	$ -	
Hydromentia, Inc.	$ 1,815,215	$ 118,765	$ 1,696,450	$ -	
QED Environmental	$ 291,655	$ -	$ 291,655	$ -	
Milking R. Dairy	$ 63,385	$ 30,026	$ 33,074	$ 285	Money transferred from Davie Dairy withdrawn leachate project in 2002
PSCG TOTAL	**$ 7,500,000**	**$ 2,686,058**	**$ 4,728,689**	**$ 85,253**	
Taylor Creek STA Land & Land Improvement	$ 8,000,000	$ -	$ 8,000,000	$ -	
Taylor Creek STA Land Acquisition Cost	$ 500,000	$ -	$ 500,000	$ -	
GRASSY ISLAND TOTAL	**$ 8,500,000**	**$ -**	**$ 8,500,000**	**$ -**	
Easement Distributions to landowners	$ 2,420,849	$ -	$ 611,107	$ 1,809,742	
3 Year Leased Employees - Staff Environmental Scientist, Senior Geographer Associate	$ 286,276	$ -	$ 161,628	$ 124,648	Planned to be expended by August 2005
Appraisal Services	$ 17,875	$ -	$ 17,875	$ -	
Restoration Implementation Contract/ Birkett Environmental	$ 875,000	$ 634,588	$ 240,412	$ -	

	Appropriation	Contract Agreement Executed / Encumbered	Expended	Balance	Comments
Restoration Implementation Contract / C&N Environmental	$ 750,000	$ 615,555	$ 134,445	$ -	
Water Quality Monitoring Contract	$ 150,000	$ 141,800	$ 8,200	$ -	
ISOLATED WETLANDS TOTAL	**$ 4,500,000**	**$ 1,391,943**	**$ 1,173,667**	**$ 1,934,390**	
L-62 Dredging / S-192 Gate & Pump Replacement	$ 1,229,095	$ 94,360	$ 938,647	$ 196,088	
PC-01-L59 Culvert Replacement	$ 169,588	$ -	$ 112,000	$ 57,588	
L-63N Dredging	$ 383,212	$ 286,954	$ 93,119	$ 3,139	
Taylor Creek Dredging Project	$ 1,218,105	$ -	$ -	$ 1,218,105	Two projects in planning process:(1) Urban Stormwater Retrofit - Lemkin Creek (468,105); (2) Taylor Creek Isles Dredging ($750,000)
STRUCTURE RETROFIT/ DREDGING TOTAL	**$ 3,000,000**	**$ 381,314**	**$ 1,143,766**	**$ 1,474,920**	
TOTAL FOR SFWMD	**$ 23,500,000**	**$ 4,459,315**	**$ 15,546,123**	**$ 3,494,563**	

SFWMD - FY02 Appropriation $10,000,000	Appropriation	Contract Agreement Executed / Encumbered	Expended	Balance	Comments
In-lake restoration projects (berm removal, Torry Island, native plant revegetation, etc.)	$ 1,800,000	$ 1,603,000	$ 193,021	$ 3,979	Transferred $150,000 to Torry Island Pond Apple Replanting
Torry Island Pond Apple Replanting	$ 150,000	$ 53,025	$ 96,975	$ -	Money Transferred from In-Lake Restoration
Public-Private BMP Partnership	$ 2,750,000	$ 2,750,000	$ -	$ -	
DEP Non-Ag Collaboration	$ 575,000	$ -	$ 575,000	$ -	
Cow-Calf BMP's	$ 450,000	$ -	$ 450,000	$ -	
Isolated Wetland Research	$ 700,000	$ -	$ 700,000	$ -	
Industrial Canal Sediment Removal	$ 500,000	$ -	$ 500,000	$ -	
Pahokee Harbor Sediment Removal	$ 250,000	$ -	$ 250,000	$ -	
Belle Glade Marina Sediment Removal	$ 250,000	$ 30,420	$ 219,580	$ -	

	Appropriation	Contract Agreement Executed / Encumbered	Expended	Balance	Comments
Glades County/Moore Haven - Stormwater/ Wastewater Plan Update	$ 250,000	$ -	$ 250,000	$ -	
Okeechobee County-Stormwater/Wastewater Plan Update	$ 175,000	$ -	$ 175,000	$ -	
Watershed Assessments	$ 232,431	$ -	$ 232,431	$ -	Transferred $167,569 to other projects (see below) in 2002
Vegetation Replanting	$ 15,400	$ -		$ 15,400	Transferred $20,000 to Torry Island Nature Center in 2002; Transferred $9,600 to Equip./Supplies
Torpedograss Control Studies	$ 110,000	$ 75,000	$ 35,000	$ -	
Model Uncertainty Refinement	$ 398,750	$ 159,454	$ 232,456	$ 6,840	Transferred $20,250 to Property Appraisal in 2002
LO Pilot Dredging Confined Disposal Facilities	$ 48,500	$ -	$ 48,340	$ 160	Transferred $8,500 from Watershed Assessments in 2002
LO Planning Contract/LO Blue Book Reporting	$ 100,000	$ -	$ 99,943	$ 57	
Expert Assistance	$ 50,784	$ -	$ 50,684	$ 100	Transferred $44,216 to LO Structure Survey
Regulatory Assessments	$ 330,000	$ -	$ 330,000	$ -	
Equipment / Supplies	$ 65,452	$ 9,200	$ 16,739	$ 39,513	Transferred $8,788 to Torpedograss Bio-Control in 2002; Transferred $6,360 to Landuse Change Analysis; Transferred $9,600 from Vegetation Replanting
3 Yr Leased Employees - Staff Engineer, Proj Mgr, Sr. Env. Scientist	$ 540,000	$ -	$ 346,505	$ 193,495	
Assessment of Water Control Practices in the Four Priority Basins	$ 159,069	$ 77,387	$ 38,068	$ 43,614	Money transferred from Watershed Assessments in 2002
Torry Island Nature Center - Design	$ 20,000	$ -	$ 20,000	$ -	Money Transferred from Vegetation Replanting in 2002
Property Appraisal	$ 20,250	$ -	$ 20,250	$ -	Money Transferred from Model Uncertainty Refinement in 2002
Torpedograss Biocontrol	$ 8,788	$ -	$ 8,788	$ -	Money Transferred from Eqmt / Supplies in 2002
LO Structure Survey	$ 44,216	$ 39,590	$ -	$ 4,626	Transferred $44,216 from Expert Assistance
Landuse Change Analysis	$ 6,360	$ 6,360	$ -	$ -	Money transferred from Equipment / Supplies

SFWMD - FY03 Appropriation $7,500,000	Appropriation	Contract Agreement Executed / Encumbered	Expended	Balance	Comments
Alternative Phosphorus Reduction Technologies Feasibility Study	$ 100,000	$ 8,303	$ 61,833	$ 29,864	
Pilot STA Performance Optimization	$ 200,000	$ 7,785	$ 1,755	$ 190,460	
LOADSS Model Upgrade	$ 50,000	$ -	$ -	$ 50,000	
Lake Okeechobee Protection Plan development	$ 110,000	$ 6,513	$ 103,380	$ 107	
S-310 Seawall Stabilization/ Industrial Canal	$ 315,000	$ -	$ 315,000	$ -	
NRCS Spectral Nutrient Evaluation	$ 100,000	$ 46,333	$ 53,667	$ -	
Optimization of Torpedograss Herbicide Treatment	$ 70,000	$ -	$ -	$ 70,000	Pending optimal water levels for treatment
Lake Okeechobee Regional Public-Private Partnership	$ 2,000,000	$ 2,000,000	$ -	$ -	
Best Available Technologies for Dairies	$ 427,750	$ 427,750	$ -	$ -	
Buck Island Ranch Study	$ 129,000		$ 126,237	$ 2,763	
BMP Implementation	$ -	$ -	$ -	$ -	BMP Implementation Projects Broken out Below ($3,748,250 total)
Implementation of Water Control Practices	$ 475,000	$ -	$ -	$ 475,000	Added $225,000 from BMP Implementation; for Mosquito Creek Gates and Telemetry
Former Dairy Restoration (5 former dairies)	$ 2,000,000	$ 2,000,000	$ -	$ -	
Milking R Dairy Isolated Wetlands Restoration	$ 500,000	$ -	$ -	$ 500,000	
Water Management Improvements	$ 386,792	$ -	$ -	$ 386,792	
Lamb Island Tributary Stormwater Treatment Project	$ 500,000	$ 500,000	$ -	$ -	
LOPP BMP Performance Analysis	$ 12,900	$ -	$ 12,900	$ -	
Lake Restoration Activities	$ 73,558	$ -	$ 73,558	$ -	
Nubbin Slough Flow Diversion	$ 50,000	$ 42,500	$ 7,500	$ -	

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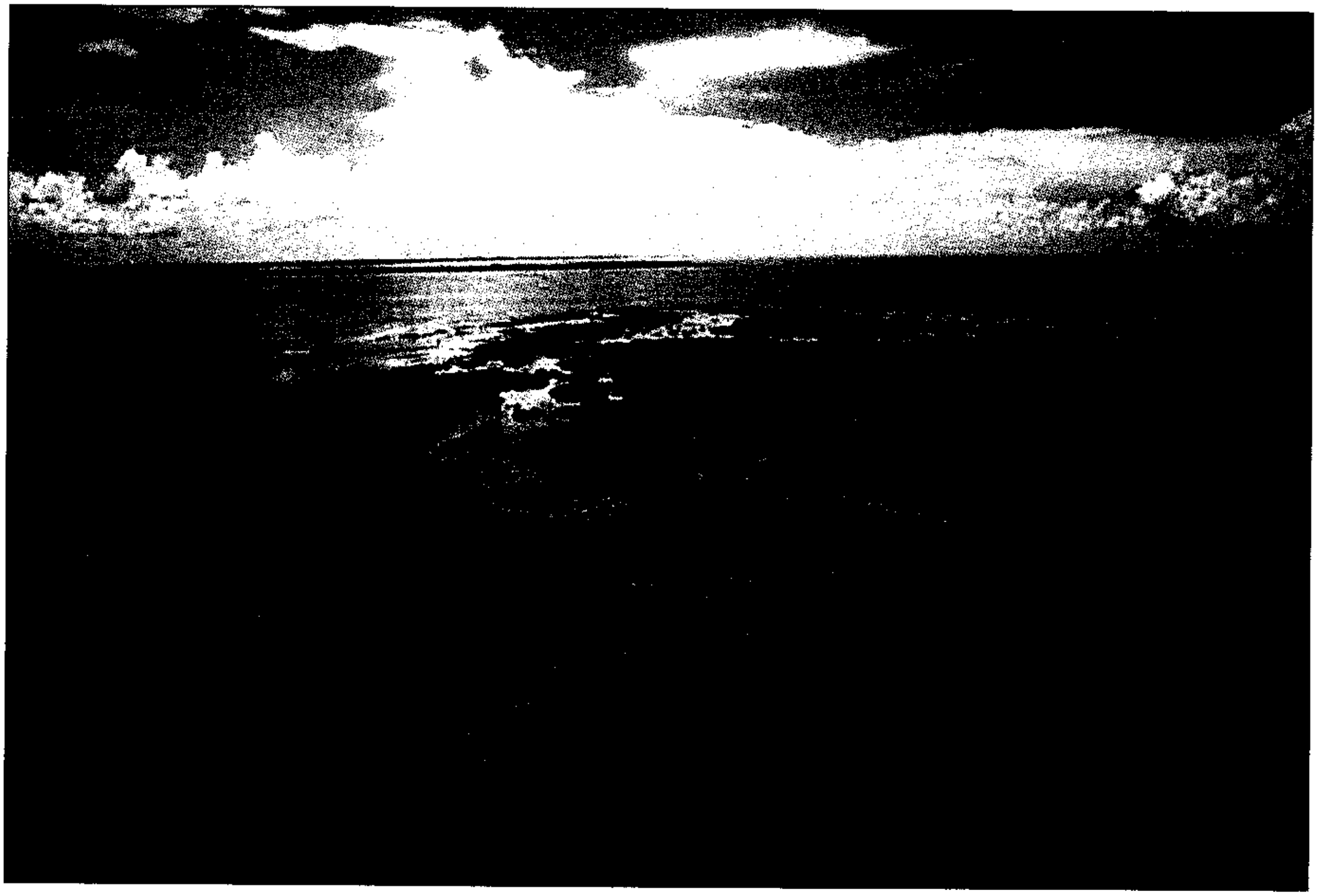
APPENDIX 1

LAKE OKEECHOBEE PROTECTION PROGRAM
EXOTIC SPECIES PLAN

LAKE OKEECHOBEE PROTECTION PROGRAM
EXOTIC SPECIES PLAN

June 1, 2002

Update: December 10, 2003



LAKE OKEECHOBEE PROTECTION PROGRAM EXOTIC SPECIES PLAN

Background

Pursuant to 373.4595(3)(e), F.S., a *Lake Okeechobee Exotic Species Control Program* was required to be developed by June 1, 2002. The statute, passed by the 2000 legislature, identified the Florida Department of Agriculture and Consumer Services (FDACS), the Florida Department of Environmental Protection (FDEP) and the South Florida Water Management District (SFWMD) as the three state agencies that would be responsible for the implementation of this statute. The Lake Okeechobee Protection Program – Program Management Plan, published in December 2001, further identified the SFWMD as the lead agency with regards to the Exotic Species Control Program.

Other agencies identified as cooperators in the statute include the Institute of Food and Agricultural Sciences of the University of Florida (IFAS), the United States Army Corps of Engineers (USACE), the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) and the Florida Fish and Wildlife Conservation Commission (FFWCC).

Pursuant to the statute, the Exotic Species Control Program is required to **1) identify the exotic species that threaten native flora and fauna within the Lake Okeechobee Watershed and 2) develop and implement measures to protect native flora and fauna.**

The area defined as the Lake Okeechobee Watershed includes Lake Okeechobee and the 39 surrounding hydrologic basins as identified in the Lake Okeechobee Surface Water Improvement and Management (SWIM) Plan (see Figure 1). Table 1 lists the primary exotic plant species and Table 2 lists the primary exotic animal species that have been identified in the Lake Okeechobee Watershed. Tables 3 through 8 are species level programs for the primary exotic plant species including principal agencies, program components and program implementation. A general discussion of exotic animal species is also included. Table 9 summarizes the FY02 expenditures for invasive exotic management within the Lake Okeechobee Watershed. Table 10 includes information on current agency management of exotic animal species.

Approach

The exotic species listed in this document are the plants and animals that have been determined to be the primary species within the Lake Okeechobee Watershed (LOW) that require management of existing invasions or, in the case of some animal species, monitoring of possible future invasions. These species lists were compiled based on discussions of interagency staff and current management efforts within the LOW. In the future, other plants and animals may be added to this list as we discover new threats or as some other minor exotic species become more dominant. In addition, while there are other exotic species within the LOW that threaten agriculture and warrant additional focus, this plan only attempts to address exotic species that threaten *native flora and fauna.*

The approach to implementation of the exotic species plan within the Lake Okeechobee watershed has been and will continue to be through the cooperative efforts of state and federal agencies. Current management efforts of these state and federal agencies include the primary exotic species that are discussed in this plan as well as other less invasive, exotic species not listed in this plan. Also, the program goal of each primary exotic plant species is "maintenance" level control. Florida law (F.S. 372.925) defines "maintenance control" as "a method of managing exotic plants in which control techniques are utilized in a coordinated manner on a continuous basis in order to maintain a plant population at the lowest feasible level." Maintenance control results in the use of less herbicides, less organic deposition in aquatic environments, less overall environmental impacts from the weeds and their management, and reduced management costs.

The species level programs outline the current and proposed management on public conservation lands within the LOW. Management efforts on private conservation lands have not been included in this document. However, public-private partnerships for the control of exotic species on private lands exist in the 2002 Farm Bill. Two major programs that came out of this legislation that will provide financial assistance to private landowners within the LOW with exotic species control are the Environmental Quality Incentives Program (EQIP) and the Wetland Reserve Program (WRP). The Wildlife Habitat Incentives Program (WHIP) will also provide some support. In calendar year 2003, two new programs are expected to come online, the Conservation Reserve Enhancement Program (CREP) and the Small Watershed Program (PL566), that will provide more aid for exotic species control to the private landowners. More information on these programs and those included in the 2002 Farm Bill can be found at www.usda.gov/farmbill.

Acronyms (in alphabetical order):

- FDACS – Florida Department of Agriculture and Consumer Services
- FDACS-DOF – Florida Department of Agriculture and Consumer Services, Division of Forestry
- FDEP – Florida Department of Environmental Protection
- FFWCC – Florida Fish and Wildlife Conservation Commission
- IFAS - Institute of Food and Agricultural Sciences of the University of Florida
- LOW – Lake Okeechobee Watershed
- SFERTF – South Florida Ecosystem Restoration Task Force
- SFWMD – South Florida Water Management District
- SFWMD-SOR – South Florida Water Management District, Save Our Rivers
- SWIM – Surface Water Improvement and Management
- USACE – United States Army Corps of Engineers
- USAF – United States Air Force
- USDA-ARS – United States Department of Agriculture, Agricultural Research Service
- USDA-NRCS - United States Department of Agriculture Natural Resources Conservation Service

Managed conservation lands surveyed for this report:

- FDACS-DOF Lake Wales Ridge State Forest
- FDEP Kissimmee Prairie State Park
- FFWCC J.W. Corbett Wildlife Management Area
- SFWMD Canals/levees
- SFWMD Lake Okeechobee marsh
- SFWMD-SOR including DuPuis, Kissimmee River properties, Nicodemus Slough
- USACE Lake Okeechobee
- USAF Avon Park Bombing Range

Timeline includes year 2000 data through 2003:

- FDEP, FDACS and FFWCC – fiscal years are from beginning of July through end of June. FY01 would be July 2000 through June 2001.
- SFWMD – fiscal years are from beginning of October through end of September. FY01 would be October 2000 through September 2000.
- USACE - fiscal years are from beginning of October through end of September. FY01 would be October 2000 through September 2000.

FIGURE 1
LAKE OKEECHOBEE WATERSHED

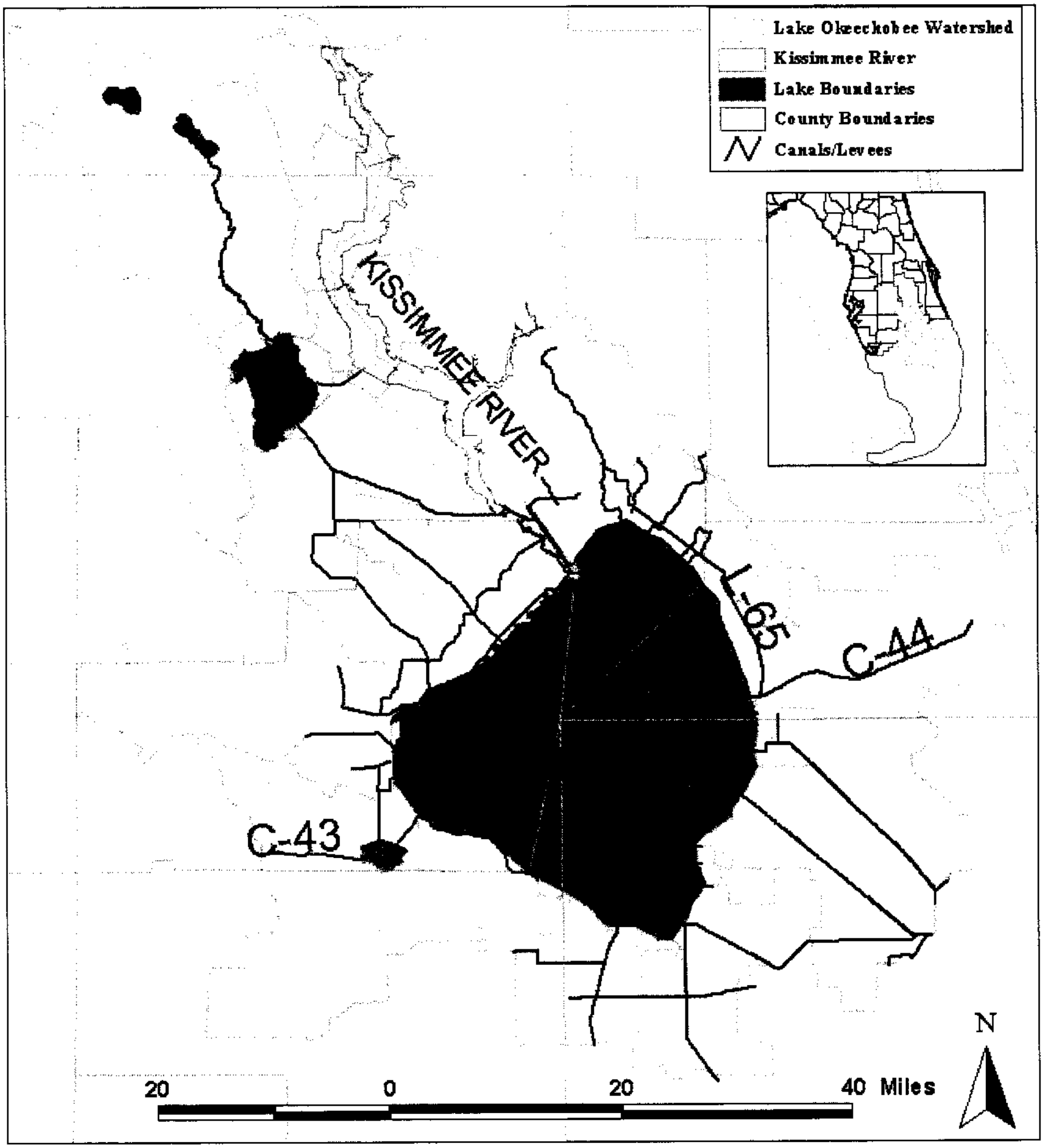


TABLE 1
EXOTIC PLANT SPECIES

Common Name	Scientific Name	Habitat(s) invaded (source: Langeland and Burks, 1998*)	Threat to flora and fauna (source: Langeland and Burks, 1998*)
Torpedograss	*Panicum repens*	In and near shallow waters; wetland marsh	Forms thick, monotypic growth, which displaces diverse native plants. Impacted areas no longer provide productive habitat for sport fish and other wildlife
Melaleuca	*Melaleuca quinquenervia*	Pine flatwoods, wetland marsh, cypress swamps	Grows extremely fast, produces dense stands, displaces native plants, diminishes animal habitat, and provides little food for wildlife.
Brazilian pepper	*Schinus terebinthifolius*	Pinelands, hardwood hammocks, roadsides, ditchbanks	Forms dense thickets of tangled woody stems that completely shade out and displace native vegetation.
Old World climbing fern	*Lygodium microphyllum*	Pinelands, tree islands, cypress swamps, wetland marsh	Forms dense, spongy mats, which are slow to decompose, excludes native understory plants and reduces plant diversity.
Hydrilla	*Hydrilla verticillata*	Freshwater: springs, lakes, marshes, ditches, rivers, tidal zones	Competitively displaces native submersed plant communities. Grows in dense stands, alters fisheries populations, causes shifts in zooplankton communities, and affects water chemistry.
Waterhyacinth	*Eichornia crassipes*	Lakes, rivers, ponds, ditches	Large mats degrade water quality and dramatically alter native plant and animal communities. Altered water chemistry results in lower fish production.
Waterlettuce	*Pistia stratiotes*	Rivers, lakes and ponds	Forms vast mats that disrupt submersed plant and animal communities.

*Langeland, K.A. and K.C. Burks, eds. 1998. Identification and Biology of Non-Native Plants in Florida's Natural Areas. University of Florida.

TABLE 2
EXOTIC ANIMAL SPECIES

Common Name	Scientific Name	Habitat(s) invaded (source: Goodyear, 2000[1])	Threat to flora and fauna (source: Goodyear, 2000[1])
Feral pig	*Sus scrofa*	Dry prairies, mesic hammocks, tropical hardwood hammocks, pine rocklands, mesic and hydric pine flatwoods, ponds, flowing waters and seepage swamps.	Rooting and trampling destroys native plant communities; disturbed areas serve as sites for exotic plant establishment and impedes wetland restoration. Harms other wildlife through direct predation and by destroying wildlife habitat.
Blue tilapia	*Oreochromis aureus*	Marshes, ponds, lakes, canals.	Competes directly with and impedes successful spawning of native fish. In Lake Okeechobee, feeds and burrows at the bottom and destroys submerged vegetation. Alters aquatic plant communities.
Asian swamp eel	*Monopterus albus*	Canals, ditches. Locally abundant and reproducing in south Broward and north Miami-Dade canals.	Well adapted to spread to sawgrass marsh and survive. This species is a potential threat to native fishes, frogs, and aquatic invertebrates.
Fire ant	*Solenopsis invicta*	Disturbed habitats, levees, pond margins, beaches, dunes, pine flatwoods, pine rocklands and hardwood hammocks.	Replaces native ant communities. Directly impacts native wildlife through predation and injury from stings. Indirect effects include reduced survival and weight gain in native invertebrates.
Spiney water flea	*Daphnia lumholtzii*	Lake Okeechobee	No impacts have been identified. At high density, they could impact larval fish and water quality.[2]
Asiatic clam	*Corbicula fluminea or C. manilensis*	Lakes, rivers, canals, ditches.	Outcompetes and can displace native mollusks. Accumulations of clamshells may change substrate and decimate populations of burrowing insects important to native fish.
Sailfin catfish (armored catfish)	*Pterygoplichthys multiradiatus*	Marshes, ponds, lakes, canals.	Competes directly with and impedes successful spawning of native fish. In Lake Okeechobee, feeds and burrows at the bottom and destroys submerged vegetation. Alters aquatic plant communities.[3]

Feral mallards	*Anas platyrhynchos*	Water bodies and adjacent uplands	Recently, domesticated strains of mallards have been released (in canals, lakes, parks, etc.) in Florida. These birds are non-migratory and interbreed with other waterfowl including Florida's native mottled duck (*Anas fulvigula fulvigula*). Hybridization compromises the mottled duck's genetic integrity and could lead to the eventual loss of this endemic duck.[4] Feral ducks also can spread diseases to wild duck populations.

[1]Goodyear, C. 2000. Draft initial status survey of nonindigenous animals in South Florida. A report by the South Florida Ecosystem Working Group.
[2]Haven, K. 2002. Personal communication. South Florida Water Management District.
[3] Fox, D. 2002. Personal communication. Florida Fish and Wildlife Conservation Commission.
[4] Moorman, T. E., and P. N. Gray. 1994. Mottled Duck. pages 1-20 in The Birds of North America, No. 81, A. Poole and F. Gill, eds., The Academy of Natural Sciences, Philadelphia, PA.

Exotic Plant Species

The following tables, Tables 3-8, have species level program components and implementations. For every species level plan the same five program components have been developed: 1) plan, 2) assess and map, 3) research, and 4) attend interagency meetings (communicate) and 5) treat. Each of these components is important to achieve a comprehensive approach to exotic plant management. The information included in the implementation column of the tables is taken from existing management efforts and future plans for exotic plant species control by state and federal agencies in the Lake Okeechobee Watershed.

TABLE 3
TORPEDOGRASS, Panicum repens

Program Goal: Bring torpedograss to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
SFWMD	1) Develop a torpedograss management **plan** for primary area(s) of infestation in LOW.	1) Management plan(s) a) Torpedograss management plan for Lake Okeechobee was completed FY01.
SFWMD	2) **Assess and map** coverage of torpedograss in LOW	2) Assess and map a) SFWMD completed a map of the Lake Okeechobee marsh vegetation distribution, which includes torpedograss, in 1996. New aerial photography scheduled to be flown in early 2003. Update of assessment and coverage to be completed in FY04.
SFWMD, FDEP	3) **Conduct research** of torpedograss biology and management studies through support programs and in-house studies.	3) Research a) Support Programs i) Biology and growth responses of torpedograss completed under SFWMD directed research grant to Army Corps of Engineers. Research grant completed FY01. ii) Research contract executed by SFWMD with University of Florida IFAS for herbicide-screening trials to develop better control methodology for torpedograss. Contract to be executed FY02 for period of 1.5 years. The first phase was completed October 30, 2003; Phase II will then be initiated for an 18 month period. iii) Research contract executed by FDEP with University of Florida to assess efficacy of fungal pathogen control of torpedograss. Research contract through June 2003. iv) IFAS biocontrol 10/02-5/03. b) In-house Studies i) A seed germination study was conducted by SFWMD to evaluate commercial seed and naturalized torpedograss seed production and viability. Initial seed germination study has shown Moroccan plants produce viable seeds, still uncertain whether naturalized populations produce viable seeds 5/02 – 5/03.
All agencies	4) **Attend** Interagency **meetings** to provide leadership and technology transfer with respect to exotic species management in LOW.	4) Meetings a) Agency staff continues to attend all Lake Okeechobee Protection Plan Interagency meetings (monthly meetings for 2001 and 2002).

TABLE 3
TORPEDOGRASS, Panicum repens

Program Goal: Bring torpedograss to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
SFWMD (FDEP provides herbicide treatment funding)	5) **Treat infestations** of torpedograss within LOW.	5) Treatment a) Herbicide i) FDEP Kissimmee Prairie State Park, have observed torpedograss, no active management. ii) SFWMD treated approximately 4,600 acres of torpedograss between June 2000 and June 2001 (FDEP FY01). From June 2001 to June 2002, approximately 5,000 acres have been treated (FDEP FY02). From June 2002 to June 2003 (FDEP FY03), SFWMD plans to treat at least 4,000 acres. Most herbicide treatments were done aerially. iii) SFWMD DuPuis Reserve, torpedograss is treated as soon as it is observed. b) Fire i) During FY01, SFWMD coordinated approximately 68,000 acres of prescribed burns in Lake Okeechobee marsh, which included torpedograss areas.

TABLE 4
MELALEUCA, *Melaleuca quinquenervia*

Program Goal: Bring melaleuca to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
All agencies	1) Develop a melaleuca management **plan** for primary area(s) of infestation in LOW.	1) Management plan(s) a) In general, most agencies follow the guidelines set forth in the Florida Exotic Pest Plant Council's Melaleuca Management Plan, May 1999, Third edition.
SFWMD	2) **Assess and map** coverage of melaleuca in LOW	2) Assess and map a) USACE has compiled a map of previously treated areas of melaleuca, Australian pine and Brazilian pepper as well as areas with treatment needs along the Okeechobee Waterway, extension levees and recreational areas. USACE will update this information in FY02. b) SFWMD completed a map of the Lake Okeechobee marsh vegetation distribution, which includes melaleuca, in 1996. New aerial photography scheduled to be flown in FY02. Update of assessment and coverage to be completed in FY03. c) SFWMD conducts a bi-annual region-wide aerial survey of target exotic pest plants on all publicly and privately owned lands (except large metropolitan areas) in southern Florida, from the north rim of Lake Okeechobee south. Target plants are melaleuca, Brazilian pepper, Old World climbing fern and Australian pine. Survey began in 1993.
SFWMD, FDEP	3) **Conduct research** of melaleuca biology and management studies through support programs and in-house studies.	3) Research a) Support Programs i) USDA-ARS melaleuca biology research in watershed with FDEP support – biocontrol agents. ii) SFWMD and USACE provide funding to USDA-ARS for biological control research. b) In-house Studies i) SFWMD has ongoing internal review of management technology to achieve best management results for control of melaleuca. ii) In FY02, SFWMD has conducted a study to assess the use of aerial surfactants to improve efficacy of melaleuca aerial treatments. SFWMD will reassess this study in FY03.
All agencies	4) **Attend** Interagency **meetings** to provide leadership and technology transfer with respect to exotic species management in LOW.	4) Meetings a) Agency staff continues to attend all Lake Okeechobee Protection Plan Interagency meetings (monthly meetings for 2001 and 2002).

TABLE 4
MELALEUCA, *Melaleuca quinquenervia*

Program Goal: Bring melaleuca to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
USACE, FFWCC, SFWMD (FDEP provides herbicide treatment funding to SFWMD and FFWCC)	5) **Treat** infestations of melaleuca within LOW.	5) Treatment a) Herbicide i) USAF Avon Park, low infestation, treats melaleuca seedlings and saplings aggressively when observed. ii) In FY01, USACE treated 2 linear miles and 82 acres as well as an additional 300 acres of mixed mature exotic vegetation and seedlings in USACE managed areas of Lake Okeechobee and the Okeechobee Waterway (OWW). In FY02, USACE plans to treat 200 acres of mixed melaleuca and Brazilian pepper as well as perform follow-up treatments and seedling removal of extensive areas along the Herbert Hoover Dike, the OWW and various levees. In FY03, USACE plans to treat 50 acres of melaleuca and Brazilian pepper within Lake Okeechobee as well as remove 10 acres of mature exotic vegetation along the OWW. iii) In FY01, USACE and SFWMD completed a joint project to treat exotic vegetation including both melaleuca and Brazilian pepper in USACE managed areas of Lake Okeechobee and the Okeechobee Waterway. iv) In Lake Okeechobee marsh, SFWMD treated 1500 acres aerially and 900 acres with ground crews in FY01. In FY02, 1200 acres will be treated aerially and 1200 acres with ground crews. In FY03, SFWMD plans to be in maintenance phase and will treat 600 acres of resprouts with ground crews. v) At DuPuis Reserve, during FY01, FY02 and FY03, SFWMD's exotic contractor treats approximately 75% of property each year. Primary species are melaleuca, Brazilian pepper and Old World climbing fern. Focus is on maintenance and treating new infestations. vi) FDEP Kissimmee Prairie State Park, have observed melaleuca, no active management. vii) At J.W. Corbett Wildlife Management Area, FFWCC treated 50 acres in FY01 and 2,750 acres in FY02. FFWCC plans to treat 2,500 acres of varying densities during FY03. b) Mechanical/manual i) In FY01, USACE removed 5 acres of dead standing melaleuca on tree islands along Okeechobee Waterway. In FY02, USACE plans on removing 5 acres of dead melaleuca along the Okeechobee Waterway. ii) SFWMD DuPuis Reserve treatments also incorporate rollerchopping. c) Fire i) During FY01, SFWMD coordinated approximately 68,000 acres of prescribed burns in Lake Okeechobee marsh, which included melaleuca areas. In FY02, SFWMD is planning a 1200 acre prescribed burn in the Moore Haven area to help control melaleuca. ii) SFWMD DuPuis Reserve treatments also include prescribed burning on a 3 year rotation. d) Biological control i) In FY02, USDA-ARS released melaleuca weevils at DuPuis. Previous releases on the Herbert Hoover Dike on west side of Lake Okeechobee.

TABLE 5
BRAZILIAN PEPPER, *Schinus terebinthifolius*

Program Goal: Bring Brazilian pepper to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
All agencies	1) Develop a Brazilian pepper management **plan** for primary area(s) of infestation in LOW.	1) Management plan(s) a) In general, most agencies follow the guidelines set forth in the Florida Exotic Pest Plant Council's Brazilian Pepper Management Plan for Florida, July 1997.
USACE, USAF, SFWMD, FDACS-DOF	2) **Assess and map** coverage of Brazilian pepper in LOW	2) Assess and map a) USACE has compiled a map of previously treated areas of melaleuca, Australian pine and Brazilian pepper as well as areas with treatment needs along the Okeechobee Waterway, extension levees and recreational areas. USACE will update this information in FY02. b) USAF Avon Park maps all exotic invasive plants on park including Brazilian pepper and Old World climbing fern. This mapping effort began 3 years ago and is planned as an ongoing project. As of FY02 quarterly reports are available with treatments and locations. Avon Park has one full time employee to monitor for exotic invasive plants in park. c) SFWMD completed a map of the Lake Okeechobee marsh vegetation distribution, which includes Brazilian pepper, in 1996. New aerial photography scheduled to be flown in FY03. Update of assessment and coverage to be completed in FY04. d) SFWMD conducts a bi-annual region-wide aerial survey of target exotic pest plants on all publicly and privately owned lands (except large metropolitan areas) in southern Florida, from the north rim of Lake Okeechobee south. Target plants are melaleuca, Brazilian pepper, Old World climbing fern and Australian pine. Survey began in 1993. e) FDACS Lake Wales Ridge State Forest maps exotic plant infestation upon field observations. Primary species includes Brazilian pepper.
SFWMD	3) **Conduct research** of Brazilian pepper biology and management studies through support programs and in-house studies.	3) Research a) Support Programs i) SFWMD provides funding to the University of Florida to research biological control. b) In-house Studies
All agencies	4) **Attend** Interagency **meetings** to provide leadership and technology transfer with respect to exotic species management in LOW.	4) Meetings a) Agency staff continues to attend all Lake Okeechobee Protection Plan Interagency meetings (monthly meetings for 2001 and 2002).

TABLE 5
BRAZILIAN PEPPER, *Schinus terebinthifolius*

Program Goal: Bring Brazilian pepper to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
USACE, FFWCC, SFWMD (some funds provided by FDEP)	5) **Treat** infestations of Brazilian pepper within LOW in accordance with Brazilian pepper management plan.	5) Treatment a) Herbicide i) USAF Avon Park treats Brazilian pepper seedlings and saplings aggressively when observed. ii) In FY01, USACE treated 95 acres of Brazilian pepper as well as an additional 300 acres of mixed mature exotic vegetation and seedlings in USACE managed areas of Lake Okeechobee and the Okeechobee Waterway. In FY02, USACE plans to treat 25 acres of Brazilian pepper, 200 acres of mixed melaleuca and Brazilian pepper as well as perform follow-up treatments and seedling removal of extensive areas along the Herbert Hoover Dike, the Okeechobee Waterway and various levees. In FY03, USACE plans to treat 50 acres of melaleuca and Brazilian pepper within Lake Okeechobee as well as remove 10 acres of mature exotic vegetation along the Okeechobee Waterway. iii) In FY01, USACE and SFWMD completed a joint project to treat exotic vegetation including both melaleuca and Brazilian pepper in USACE managed areas of Lake Okeechobee and the Okeechobee Waterway. iv) In Lake Okeechobee marsh, SFWMD treated 500 acres aerially in FY01. In FY02, 300 acres will be treated with ground crews on levees and the mud canal. In FY03, SFWMD plans to be in maintenance phase and will treat resprouts with ground crews only. v) In Kissimmee River Valley, SFWMD treated approximately 500 acres in FY01. In FY02, 200 acres will be treated. In FY03, treatment as time allows, primary focus will be Old World climbing fern. vi) At DuPuis Reserve, during FY01, FY02 and FY03, SFWMD's exotic contractor treats approximately 75% of property each year. Primary species are melaleuca, Brazilian pepper and Old World climbing fern. Focus is on maintenance and treating new infestations. vii) FDEP Kissimmee Prairie State Park, have observed Brazilian pepper, no active management. viii) FDACS-DOF Lake Wales Ridge State Forest routinely treats Brazilian pepper as soon as it is observed. ix) At J.W. Corbett Wildlife Management Area, FFWCC treats approximately 10 acres each year as observed. b) Mechanical/manual i) SFWMD DuPuis Reserve treatments also incorporate rollerchopping. c) Fire i) SFWMD DuPuis Reserve treatments also incorporate prescribed burning on a 3 year rotation.
+	**6)**	6)

TABLE 6
OLD WORLD CLIMBING FERN, *Lygodium microphyllum*

Program Goal: Bring Old World climbing fern to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
All agencies	1) Develop a Old World climbing fern management **plan** for primary area(s) of infestation in LOW.	1) Management plan(s) a) In general, most agencies follow the guidelines set forth in the Florida Exotic Pest Plant Council's Lygodium Management Plan for Florida, 2001, First Edition.
USAF, SFWMD, FDACS	2) **Assess and map** coverage of Old World climbing fern in LOW	2) Assess and map a) USAF Avon Park maps all exotic invasive plants on park including Brazilian pepper and Old World climbing fern. This mapping effort began 3 years ago and is planned as an ongoing project. As of FY02 quarterly reports are available with treatments and locations. Avon Park has one full time employee to monitor for exotic invasive plants in park. b) SFWMD conducts a bi-annual region-wide aerial survey of target exotic pest plants on all publicly and privately owned lands (except large metropolitan areas) in southern Florida, from the north rim of Lake Okeechobee south. Target plants are melaleuca, Brazilian pepper, Old World climbing fern and Australian pine. Survey began in 1993. c) FDACS Lake Wales Ridge State Forest maps exotic plant infestation upon field observations. Monitoring for new infestations of climbing fern.
SFWMD	3) **Conduct research** of Old World climbing fern biology and management studies through support programs and in-house studies.	3) Research a) Support Programs i) SFWMD provides funding to USDA-ARS for biocontrol research annually. ii) SFWMD, through a USDA contract, provides funding to the Institute for Regional Conservation to conduct annual long-term monitoring of expansion in different habitats including undisturbed flatwoods at J.W. Corbett and roller-chopped flatwoods at DuPuis. iii) SFWMD and University of Florida, Center for Aquatic and Invasive Plants are conducting and on-going assessment of efficacy and non-target damage post aerial treatment and throughout follow-up ground crew treatment operations at Corbett and DuPuis. b) In-house Studies i) SFWMD DuPuis, performing in-house study to show the difference of treatment vs. no treatment in flatwoods within normal management activities (rollerchopping and then 3 year prescribed burn rotation). Past years have performed herbicide screening trials both aerially and with ground crews and in different ecosystems.

TABLE 6
OLD WORLD CLIMBING FERN, *Lygodium microphyllum*

Program Goal: Bring Old World climbing fern to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
All agencies	4) **Attend** Interagency **meetings** to provide leadership and technology transfer with respect to exotic species management in LOW.	4) Meetings a) Agency staff continues to attend all Lake Okeechobee Protection Plan Interagency meetings (monthly meetings for 2001 and 2002).
USAF, SFWMD, FDEP, FFWCC (some funds provided by FDEP and SFWMD)	5) **Treat** infestations of Old World climbing fern within LOW in accordance with Old World climbing fern management plan.	5) Treatment a) Herbicide i) USAF Avon Park treated both *Lygodium microphyllum* and *Lygodium japonicum* in FY01 and FY02. FY01 treated small outlier infestations throughout 23,000-acre cypress area. FY02 finished initial treatments of small infestations, now treating large (~100 acre) infestations throughout cypress area. FY03 will complete initial treatments of large infestations and start retreating all initial plots. ii) In Kissimmee River Valley, SFWMD treated small infestations in FY01. In FY02, 700 acres of Old World climbing fern will be treated aerially and 235 acres with ground crews. In FY03 1000 acres will be treated aerially and 220 acres with ground crews. FY03 ground treatments will target retreatment in FY02 ground crew areas. iii) At DuPuis Reserve, during FY01, FY02 and FY03, SFWMD's exotic contractor treats approximately 75% of property each year. Primary species are melaleuca, Brazilian pepper and Old World climbing fern. Focus is on maintenance and treating new infestations. iv) FDEP Kissimmee Prairie State Park, have observed Old World climbing fern, no active management. Treated small outlier area in FY02. v) At J.W. Corbett Wildlife Management Area, FFWCC treated 300 acres aerially and 750 acres with ground crews in FY01 and 27 acres with ground crews in FY02. FFWCC plans to treat 350 acres of dense infestation in FY03. b) Mechanical/manual i) SFWMD DuPuis Reserve treatments also incorporate rollerchopping. c) Fire i) SFWMD DuPuis Reserve treatments also incorporate prescribed burns on a 3 year rotation.

TABLE 7
HYDRILLA, *Hydrilla verticillata*

Program Goal: Bring primary submersed aquatic plants to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
USACE, SFWMD	1) Develop a submersed aquatic plant management **plan** for primary area(s) of infestation in LOW.	1) Management plan(s) a) Lake Okeechobee and Kissimmee River aquatic plant management plans developed in the 1990s. This plan is revised as needed through interagency processes.
USACE, FDEP, SFWMD	2) **Assess and map** coverage of submersed aquatic plants in LOW	2) Assess and map a) USACE and interagency members informally assess in Lake Okeechobee and watershed during frequent inspections. b) FDEP formally surveys all State Waters annually. c) SFWMD formally monitors submersed aquatic plant populations through ongoing surveys in Lake Okeechobee- annually.
	3) **Conduct research** of submersed aquatic plant biology and management studies through support programs and in-house studies.	3) Research a) Support Programs i) Hydrilla resistance to herbicides conducted by IFAS, funds FDEP. Start 02-03 b) In-house Studies
All agencies	4) **Attend** Interagency **meetings** to provide leadership and technology transfer with respect to exotic species management in LOW.	4) Meetings a) Agency staff continues to attend all Lake Okeechobee Protection Plan Interagency meetings (monthly meetings for 2001 and 2002).
USACE, USDA-ARS, SFWMD (FDEP provides SFWMD funding for herbicide treatment in state waters outside Lake Okeechobee)	5) **Treat** infestations of submersed aquatic plants within LOW in accordance with submersed aquatic plant management plan.	5) Treatment a) Herbicide i) In SFWMD canals within the LOW, approximately 3 acres of hydrilla were treated in FY01. SFWMD plans to treat 20 acres of hydrilla during FY02 and FY03. ii) In FY01, SFWMD did not treat hydrilla in State Waters within the LOW (i.e. Old Kissimmee River, Taylor Creek, Lake Okeechobee tributaries and C-38). There are no projected treatments for FY02. In FY03, SFWMD estimates treating 100 acres in State Waters in LOW. b) Mechanical/manual i) USACE conducts harvesting in Lake Okeechobee. ii) SFWMD conducts occasional harvesting of submerged aquatic plants when densely collected in channels and water control structures. c) Biological control i) USDA-ARS performs ongoing monitoring of introduced hydrilla biocontrol insects.

TABLE 8
WATERHYACINTH, *Eichornia crassipes*
WATERLETTUCE, *Pistia stratiotes*

Program Goal: Bring primary floating aquatic plants to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
USACE, IFAS, FDEP, FFWCC, SFWMD	1) Develop a floating aquatic plant management **plan** for primary area(s) of infestation in LOW.	1) Management plan(s) a) Lake Okeechobee and Kissimmee River aquatic plant management plans developed in the 1990s. Revised as needed through interagency processes.
USACE, FDEP, FFWCC, SFWMD	2) **Assess and map** coverage of floating aquatic plants in LOW	2) Assess and map a) Ongoing USACE inspections of Lake Okeechobee. b) Interagency group aerially inspects Lake Okeechobee bi-monthly. FDEP formally surveys all State Waters annually.
USDA-ARS	3) **Conduct research** of floating aquatic plant biology and management studies through support programs and in-house studies.	3) Research a) Support Programs i) USDA-ARS performs ongoing monitoring of introduced water hyacinth and waterlettuce biocontrol insects. b) In-house Studies
All agencies	4) **Attend** Interagency **meetings** to provide leadership and technology transfer with respect to exotic species management in LOW.	4) Meetings a) Agency staff continues to attend all Lake Okeechobee Protection Plan Interagency meetings (monthly meetings for 2001 and 2002).

TABLE 8
WATERHYACINTH, *Eichornia crassipes*
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Program Goal: Bring primary floating aquatic plants to maintenance level control in the Lake Okeechobee watershed

Principle Agency(s)	Program Components	Program Implementation
USACE, FFWCC, FDEP, SFWMD (FDEP provides SFWMD funding for herbicide treatment in State Waters)	5) **Treat** infestations of floating aquatic plants within LOW in accordance with floating aquatic plant management plan.	5) Treatment a) Herbicide i) USACE treated 733 acres of floating plants in FY01. This number is low due to the drought. In FY02, USACE will treat approximately 7200 acres, and plans to treat 5000 acres in FY03. ii) In SFWMD canals within the LOW, approximately 1888 acres of waterlettuce and waterhyacinth were treated in FY01, 1195 acres of waterlettuce and waterhyacinth will be treated in FY02, and SFWMD plans to treat 4078 acres of waterlettuce and waterhyacinth in FY03. iii) SFWMD DuPuis Reserve routinely treats waterhyacinth and waterlettuce in the east, west and borrow ditches of the marsh every 4 months. iv) In FY01, SFWMD treated 947 acres of floating plants in State Waters within the LOW (i.e. Old Kissimmee River, Taylor Creek, Lake Okeechobee tributaries and C-38). In FY02, SFWMD plans on treating approximately 700 acres. In FY03, SFWMD estimates treating 600 acres in State Waters in LOW. v) FDACS-DOF Lake Wales Ridge State Forest treats waterhyacinth as soon as it is observed either chemically or manually (pull out of waterbody). vi) At J.W. Corbett Wildlife Management Area, FFWCC treats approximately 1 mile of waterhyacinth each year in internal canals. b) Mechanical/manual i) USACE, in Lake Okeechobee harvests densely collected floating plants as necessary. These efforts are done every year, on an as needed basis. ii) SFWMD, in other public waters of the LOW, harvests densely collected floating plants as necessary, usually near water management structures or from navigation channels. These efforts are done every year, on an as needed basis. FDACS-DOF Lake Wales Ridge State Forest treats waterhyacinth as soon as it is observed either chemically or manually (pull out of waterbody) c) Biological control i) Waterhyacinth and waterlettuce biocontrol insects were previously introduced into waterbodies in the LOW.

TABLE 9
FY02 EXOTIC PLANT SPECIES EXPENDITURES

Exotic Species	Agency	Costs*	Action
Lygodium	FDACS-DOF, Lake Wales Ridge State Forest	$24,000	90-95% of money spent on lygodium and on cogon grass. Lesser extent of treatment for star grass, Brazilian pepper, mimosa, camphor tree, air potato, tropical soda apple and rosary pea.
Melaleuca, lygodium, Brazilian pepper, hydrilla/ hyacinth	SFWMD- managed	$644,000	Primary species are lygodium, melaleuca and Brazilian pepper.
Melaleuca, lygodium, Brazilian pepper	FFWCC, J.W. Corbett Wildlife Management Area	$710,000	10 acres of pepper, 52 acres of melaleuca, 112 acres of lygodium; 1250 acres of melaleuca and lygodium retreatment
Lygodium	USAF Avon Park	$135,000	Primarily Old World climbing fern. Follow up treatments on Brazilian pepper and strawberry guava. In- house crews treated cogon grass and tropical soda apple.
Cogon grass	FDEP, Kissimmee Prairie State Park	$12,000	Currently (not FY02) treating cogon grass, air potato, lygodium, and tropical soda apple. Plan on treating Brazilian pepper and lygodium with DEP grant. Have a feral pig contract and will treat fire ants as needed.
Torpedograss, melaleuca, Brazilian pepper	SFWMD, Lake Okeechobee marsh	$1,647,000	Torpedograss treatment only on Lake Okeechobee marsh. Melaleuca treatment only throughout Lake Okeechobee. Brazilian pepper treatment throughout Lake Okeechobee.
Melalueca, Brazilian pepper	USACE, Lake Okeechobee waterway and HH Dike	$1,296,000	Includes $1,021,328 on floating vegetation and tussocks. Remainder of funds used to treat melaleuca, Brazilian pepper, Australian pine and bamboo.
Hydrilla/hyacinth	SFWMD, Lake Okeechobee, canals	$143,000	Includes funding for floating, emerged, submersed and ditchbank treatments on L-8, L-19, L-12, L-13, L-14, L-20, L-25, C-19, C-20, C-21, C-43, L-41, L-42
Brazilian pepper, melaleuca	SFWMD, Nicodemus Slough	$5,000	$4500 was for Brazilian pepper and $500 was for melaleuca.
Lygodium	SFWMD, Kissimmee River basin	$230,000	Lygodium, both ground and aerial, in Kissimmee River Pools.
Total		**$4,846,000**	

- Costs may include treatment for other invasive plants, in addition to the major exotic species.

Exotic Animal Species

The effort to address exotic animals in Florida has lagged behind that of invasive plants. While it is relatively easy to determine the extent to which exotic plants invade native areas, the impact of exotic animals on native communities and on those species with which they compete directly is frequently less obvious

The South Florida Ecosystem Restoration Task Force (SFERTF)-Working Group has been gathering information in the south Florida area as a basis for an assessment of the problem. The LOW is within the area assessed. In February 1998, the Working Group established an ad hoc interagency team to focus on South Florida and evaluate the status of non-indigenous animals in all habitats (freshwater, marine and terrestrial), describe efforts underway to deal with them, and identify agency needs and problems. Non-native animal species of concern include insects, marine and freshwater fish and invertebrates, reptiles and amphibians, mammals and birds. This non-native animal report was submitted to the Working Group in February 2000 in order to provide a broad picture of the status of non-indigenous animal species in South Florida. It focuses on the agencies, along with their respective departments, that are represented on the Working Group. It is hoped that this report will be used as a basis for the Working Group to evaluate its members' priorities relative to non-indigenous animals and to determine if and how it might assist the work of individual agencies, enhance interagency collaboration, and integrate South Florida efforts into state, regional, or national programs. The ultimate goal of any further efforts would be to develop a system-wide action plan to address non-indigenous animals in the South Florida ecosystem.

The following table, Table 10, lists current agency actions within the LOW with regards to the primary exotic animal species identified in Table 2. The coordinating agencies of the Lake Okeechobee Protection Program, FDEP, FDACS and SFWMD will begin discussions during the Lake Okeechobee Protection Plan Interagency meetings with the FFWCC and other cooperating agencies to determine future necessary actions to be taken with regards to exotic animal species. In addition, as more information is provided by the Working Group as to an action plan for non-indigenous animals in South Florida, the coordinating agencies will make efforts to incorporate these recommendations into future revisions of this plan.

TABLE 10
EXOTIC ANIMAL SPECIES MANAGEMENT

Exotic Animal	Agency	Action
Feral pig	USAF, Avon Park	Up to 2001, primary management of feral pigs has been through hunting. The year 2000 (August through late December) hunt had a harvest of 508 pigs. The year 2001 hunt had a harvest of 271 (park was closed due to security restrictions after September 11, 2001). Beginning in 2001, management has included trapping of feral pigs on the unhunted lands. Between November 2001 and March 2002 (breeding peak), 276 pigs were trapped. Future plans for management include both hunting and trapping. USAF conducts an annual pig survey every August.
	FDACS-DOF, Lake Wales Ridge State Forest	Management consists of allowing hunting for feral pigs.
	SFWMD-SOR	Planning on trapping feral pigs in KICCO area of Kissimmee River in FY03. This will be first management effort to utilize trapping on SOR lands. This will be coordinated with FFWCC. FFWCC manages game animal hunts, which includes feral pigs on KICCO and Hickory Hammock (both wildlife management areas) based on quota hunts. FFWCC also manages hunts on Kissimmee River and DuPuis SOR lands that are open to hunting.
	FDEP, Kissimmee Prairie State Park	Trapped over 700 feral pigs in FY01.
	FFWCC, J.W. Corbett Wildlife Management Area	Management consists of allowing hunting for feral pigs. Average harvest per year is 150 to 250 pigs.
Blue tilapia	FDEP, Kissimmee Prairie State Park	Observed in park, allow fishing for consumption, otherwise no activity.
	SFWMD, Lake Okeechobee	Observed by SFWMD staff as abundant in Lake Okeechobee. No current treatment.
Asian swamp eel	SFWMD, Lake Okeechobee	None observed. No current treatment in Lake Okeechobee. Have been observed in SFWMD Canals in Broward and Miami-Dade counties.
Fire ant	FDEP, Kissimmee Prairie State Park	Treat fire ants as an ongoing project. Spent $500 on fire ants in FY01.
Spiney water flea	SFWMD, Lake Okeechobee	Monitoring done monthly at 5 locations in the Lake Okeechobee's open-water region
Asiatic clam	SFWMD, Lake Okeechobee	Observed by SFWMD staff as abundant in Lake Okeechobee. No current treatment.
Sailfin catfish	FFWCC	Observed in Miami north to West Palm Beach also in Lake Okeechobee. No current treatment.
Feral Mallard	FFWCC	FFWCC has initiated a comprehensive program to educate the public

TABLE 10
EXOTIC ANIMAL SPECIES MANAGEMENT

Exotic Animal	Agency	Action
		about the serious problems feral mallards cause in order to increase awareness and reduce the number of mallards illegally released in the state. FFWCC also has secured a permit from the USFWS to control nuisance feral mallards, and is working to develop a sub-permitting process to allow local entities to control nuisance mallards between the months of May through September. Note: wild mallards migrate into (winter months) and out (spring) of Florida and are a natural part of the bird community. Mallard control efforts will target only the feral non-migratory birds that remain in the state during the spring and summer (i.e., the mottled duck breeding period), thus posing a hybridization threat to mottled ducks. Contact FFWCC's waterfowl program at 321-726-2862 or http://wld.fwc.state.fl.us/duck/ for further information

APPENDIX 2

LAKE OKEECHOBEE PROTECTION PROGRAM
WATER QUALITY BASELINE FOR PHOSPHORUS

Lake Okeechobee Protection Program
Water Quality Baseline for Phosphorus

June 30, 2002

Hydro Information Systems and
Assessment Division
South Florida Water Management District

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Executive Summary

The purpose of this baseline is to elucidate and summarize significant trends for total phosphorus (TP) and ortho-phosphorus (OPO4) in Lake Okeechobee collected from November 6, 1973 through October 16, 2001. Having this baseline information is critical for evaluation of future changes in TP and OPO4 trends that might be expected to occur upon the completion of the Lake Okeechobee Protection Program (Chapter 00-130, Florida Statutes).

For the purpose of evaluating regional trends the lake was divided into six regions: Pelagic, North and South Near Shore, North Littoral, South Littoral, and Fisheating Bay. Initially, only the pelagic region was sampled. The near-shore stations were sampled after a major algal bloom in 1986 impacted that area of the lake. The littoral stations were added later, due to concerns that P-rich pelagic water was entering that pristine zone of the lake under high stage conditions. The current monitoring program encompasses 30 locations, which provide the representative information to characterize the quality of water throughout the lake regions. For statistical purposes, monthly and yearly data were considered to establish trends. Summary statistics, time series graphs, seasonal Kendall's Tau and the Analysis of Covariance were used to determine the presence of significant trends for the two water quality parameters over the period of record.

Results presented in this report shows significant water quality changes in the Pelagic region over the 30-year period of record. The seasonal Kendall's Tau Test found a strong evidence of a linear increasing trend for TP and OPO4 in this region. Although there is some evidence of an increasing trend in TP for the North Littoral Region and Fisheating Bay, there are not sufficient data to support the determination of statistically significant trends in total concentrations about these regions. A longer period of record is necessary in order to support the significance of these findings. The results of this baseline support the need to continue sampling at these monitoring stations.

INTRODUCTION

Overview of Lake Okeechobee Protection Program

The Lake Okeechobee Protection Program (Chapter 00-130, Florida Statutes) was passed by the Florida Legislature in 2000. This program committed the State of Florida to restore and protect Lake Okeechobee. This will be accomplished by achieving and maintaining compliance with water quality standards in Lake Okeechobee and its tributary waters, through a watershed-based, phased, comprehensive and innovative protection program designed to reduce phosphorus loads and implement long-term solutions, to meet the Lake's Total Maximum Daily Load (TMDL) for phosphorus. The program sets forth a series of activities and deliverables for the coordinating agencies: the South Florida Water Management District (hereafter, District); the Florida Department of Environmental Protection (FDEP); and the Florida Department of Agriculture and Consumer Services (FDACS). Section (3)(d)1 of the 2000 Florida Statutes (373.4595) requires that the District develop a water quality baseline to represent existing conditions for total phosphorus. This section of the Statutes makes particular reference to the watershed, in regard to establishing this baseline. The watershed includes both Lake Okeechobee proper, and the surrounding basins that contribute surface water runoff and phosphorus inputs to the Lake. This report summarizes baseline information on total phosphorus (and ortho-phosphorus, which is the form readily available to plants and algae) for Lake Okeechobee, including the pelagic, near-shore, and littoral zones. A subsequent report will summarize baseline information on total phosphorus for the surrounding tributary basins.

Water Quality and Habitat Conditions in Lake Okeechobee and the Watershed

Lake Okeechobee functions as the central part of a large, interconnected aquatic ecosystem in South Florida and as the major surface water reservoir of the Central and Southern Florida Flood Control Project. The lake provides a number of values to society and nature including water supply for agriculture, urban areas, undeveloped areas, flood protection, and multimillion-dollar sport and commercial fishing industries. It also provides habitat for wading birds, migratory waterfowl, and the federally endangered Everglades Snail Kite. These benefits of the lake have been threatened in recent decades by excessive phosphorus loading, harmful high and low water levels, and rapid expansion of exotic plants (LOPP, 2002).

Specific Issues of Concern for Phosphorus

- Total phosphorus concentrations in the lake have doubled since the early 1970s, now averaging approximately 120 parts per billion (ppb).
- There is a high rate of phosphorus loading from both the watershed (external loads) and from the mud sediments within the lake (internal loads).
- The in-lake sediments may be losing their ability to assimilate phosphorus and may be contributing to the increased phosphorus concentration in the lake.
- Phosphorus-rich mud sediments at mid-lake are frequently resuspended by wind and transported to ecologically sensitive shoreline areas especially during times of high lake levels (LOPP, 2002).
- Cattail has expanded in areas of the littoral marsh, directly in contact with phosphorus-enriched water.

Baseline Development-Data Analysis Period

Section (3)(d)1 (Chapter 00-130, Florida Statutes) requires the District to submit an annual monitoring report to the legislature providing updates on water quality data and associated comparisons with state water quality standards. The water quality characterization includes an evaluation of compliance with Class I criteria for each monitoring location representative of Lake Okeechobee in-lake stations and the development of a water quality baseline for phosphorus.

This is the first in-lake water quality baseline for Lake Okeechobee regarding historic and existing conditions for total phosphorus (TP) and ortho-phosphorus (OPO4). The purpose of this report is to elucidate and summarize significant trends for TP and OPO4 in Lake Okeechobee collected from November 6, 1973 through October 16, 2001. Having this baseline information is critical for evaluation of future changes in TP and OPO4 trends that might be expected to occur upon completion of the protection program.

Historical data from the sampling stations were previously analyzed in several papers (e.g., Havens 1994a, Havens et al., 1994, James et al., 1995).

LAKE REGIONS

The current monitoring program encompasses 30 locations, which provide the representative information to characterize the quality of water throughout the lake (Fig.1). The representative water quality monitoring locations, names, number of samples, and collection period of the various categories of phosphorus constituents, denoted in the management plan, are shown in Table 1 **(Appendix A)**.

For the purpose of evaluating regional trends in TP and OPO4, the lake was divided into six regions. The first region (pelagic) was represented by stations L001 to L008, the historic monitoring stations that have been sampled by the District since 1973. These eight stations are identified in the supporting documents for the Total Maximum Daily Load (TMDL, FDEP 2000); the average TP concentration at these stations is used to track progress towards a pelagic goal of 40 ppb. At times, the pelagic region can display heterogeneity in terms of TP and OPO4 concentrations, but the extent varies with lake stage. For the purpose of this report, to be consistent with the TMDL evaluation protocol, the region is considered as a whole.

Two additional regions (north and south near-shore) occur along the northwest and south to southwest shoreline of the lake. The stations in these regions occur in areas of shallow water, with a high density of submerged plants when water levels in the lake are low, and periodic blooms of blue-green algae when water levels are high. Data from these stations were used in the process of identifying the lake TP goal for the TMDL, using chlorophyll–TP empirical modeling (Havens and Walker, 2002). The near-shore stations encompass a region where blooms of blue-green algae are most responsive to changes in TP (especially in the south), and they also represent a region of the lake that is heavily visited by sport fish, wildlife, and humans. Drinking water intakes for several local municipalities occur in the near-shore area.

The last three regions are north littoral, south littoral, and Fisheating Bay. These regions, along the western side of the lake, differ in regard to vegetation structure and water quality. The north littoral region has a high density of torpedo grass and cattail, with relatively low levels of TP. The south littoral region has a diverse community of native marsh plants and very low levels of TP. The north and south littoral regions receive most of their phosphorus inputs from rainfall when water levels in the lake are low, and may receive inputs of phosphorus from the pelagic region when water levels are high (Steinman et al., 1998). The Fisheating Bay region is heavily influenced by water inputs from Fisheating Creek, and from transport of water and re-suspended sediment materials when water levels in the lake are high and under the influence of wind-driven currents (Havens et al., 2000).

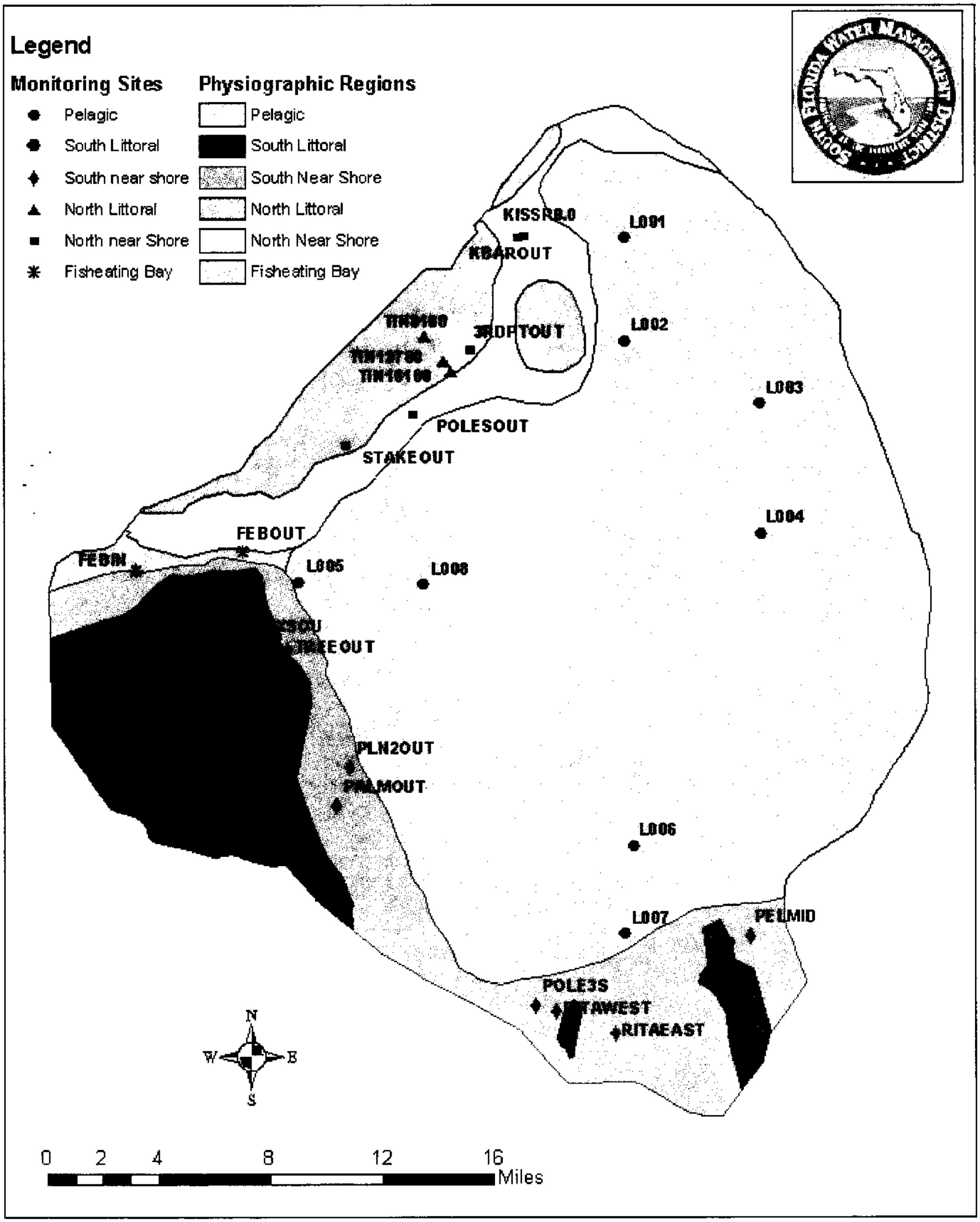


Figure 1. Physiographic regions and monitoring sites in Lake Okeechobee

METHODS

Water Quality Data

The water quality data evaluated in this report were retrieved from the South Florida Water Management District's DBHYDRO database. This is the repository for all regular water quality data collected on the Lake.

Sample collection on Lake Okeechobee is accomplished mainly through a grab-sample program. Grab samples are collected in the pelagic region on a biweekly basis during the rainy season (June-October) and monthly during the dry season (November–May). Collection occurs on a monthly basis for the littoral region and nearshore stations. TP and OPO4 concentrations are determined by standard method SM4500-P F.

Method Detection Limits

Each water quality constituent has a Method Detection Limit (MDL) that essentially defines the minimum concentration at which the constituent can be analytically quantified. The MDL is usually twice the background noise level associated with a test and will not represent an exact measurement. The Practical Quantitation Limit (PQL) represents a higher level of measurement certainty, i.e., greater precision, for a constituent than the MDL and is generally considered to be the lowest level achievable among laboratories within specified limits during routine laboratory operations. The District lab establishes the PQL at four times the MDL.

In this report, data reported to be less than the MDL were assigned a value of ½ the MDL. TP and OPO4 data less than the MDL of four parts per billion (ppb), were assigned a value of two ppb.

Descriptive Statistical Analysis

A description of the data (summary statistics, **Table 1a**) in this report is complemented by a graphical representation of the data sets for TP and OPO4, which are presented in time series graphs and box plots. For statistical purposes, monthly and yearly data were considered to establish trends. In the case where multiple samples were collected within a given month, arithmetic means were calculated. Basic statistics reported here include number of samples, means, medians, minima, maxima, and standard deviations for each of the 30 stations (Table 3,

Appendix A). Additional in-depth analyses of each lake region are included using the seasonal Kendall's Tau and the Analysis of Covariance (ANOCOVA) to determine the presence of trends for the two water quality parameters over the period of record. Initially, only the pelagic region was sampled. The near-shore stations were sampled after a major algal bloom in 1986 impacted that area of the lake. The littoral stations were added later, due to concerns that P-rich pelagic water was entering that pristine zone of the lake under high stage conditions.

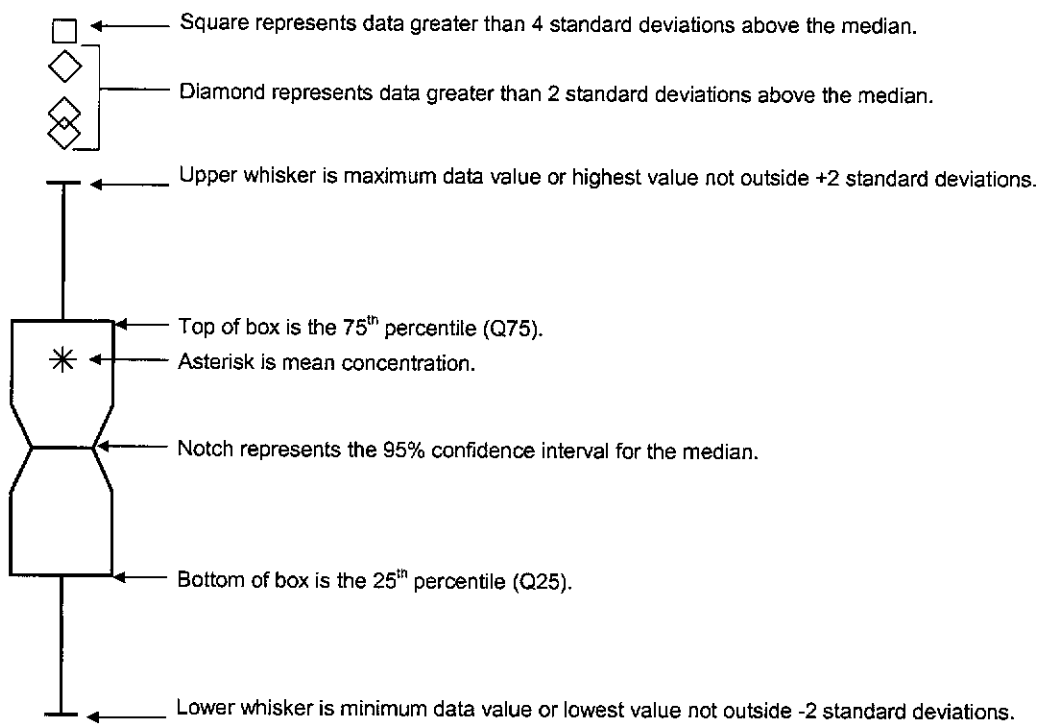
Table 1a. Summary Statistics for the Lake Regions

Fisheating Bay	OPO4	83	0.0370	0.0498	0.0140	0.0020	0.2370	96-01
Fisheating Bay	TP	82	0.1124	0.0811	0.1080	0.0180	0.6130	96-01
Pelagic	OPO4	2539	0.0241	0.0208	0.0190	0.0008	0.1230	72-01
Pelagic	TP	2545	0.0894	0.0458	0.0810	0.0100	0.3290	72-01
North Littoral	OPO4	117	0.0115	0.0127	0.0070	0.0020	0.0700	96-01
North Littoral	TP	117	0.0606	0.0477	0.0530	0.0040	0.2070	96-01
North near Shore	OPO4	774	0.0196	0.0263	0.0090	0.0020	0.1800	86-01
North near Shore	TP	788	0.0792	0.0413	0.0680	0.0130	0.3225	86-01
South Littoral	OPO4	185	0.0120	0.0663	0.0040	0.0020	0.8550	96-01
South Littoral	TP	178	0.0251	0.0758	0.0140	0.0020	0.9350	96-01
South near Shore	OPO4	998	0.0137	0.0188	0.0055	0.0010	0.1290	86-01
South near Shore	TP	1013	0.0618	0.0416	0.0510	0.0020	0.3050	86-01

Description Of Notched Box-And-Whisker Plots

Notched box-and-whisker plots were created in this report to display and summarize selected statistical properties of the data sets (Table 2). These plots have been used to test for statistical significance between data sets at roughly a 95-percent confidence interval, to detect changes in constituent concentration variability over time, and to determine if trends exist. Notched box-and-whisker plots consist of the median, the lower quartile, the upper quartile, the smallest and the largest values in the distribution of a given set of data. The central box represents the values from the lower to upper quartiles (25th to 75th percentile). The middle line represents the median of the data, and the notch in the box is the 95-percent confidence interval of the median. When notches between boxes do not overlap, the medians are considered significantly different. The notched box-and-whisker plot used for these summaries follows McGill et al. 1978.

Table 2. Description of Notched Box-and-Whisker Plots Used in this Report



1. Notches surrounding the medians provide a measure of the significance of differences between notched box plots If the notches about two medians do not overlap, the medians are significantly different at about a 95 percent confidence level.

2. At times the variability in a data set may be quite high. When highly variable data are presented in a notched box and whisker plot, the width of the notch may be greater than the 25th or 75th percentile. When this occurs, the box plot appears as if it is folded from the end of the notch back towards the median. This is done automatically by the statistic program to save space within the figure being presented.

3. Notches are calculated using the following equation:

$$Notch = Median \pm \frac{1.58\,(Q75 - Q25)}{\sqrt{n}}$$

Where: n = number of data points

Description Of Seasonal Kendall's Tau

The seasonal Kendall's Tau is a non-parametric test frequently used for analysis of water quality time series. It is a rank-order statistic that can be applied to time series exhibiting seasonal cycles, missing and censored data, and indications of non-normality (Yu and Zou, 1993). For the purpose of this report evaluation, $p\ \alpha\ 0.05$ was selected to indicate statistical significance. Results of the Kendall's Tau test can indicate if statistically significant differences in TP and OPO4 are present between the pelagic stations and the littoral regions.

Description Of The ANOCOVA

Parametric ANOCOVA was used in this report to assess whether data sets from different regions have different averages with a significance set at $p\ \alpha\ 0.05$. This test analyzes data where more than two groups or conditions are used. It is also used instead of many pairwise *t* tests in order to hold the probability of making a Type I error at α (Pagano *et al.* 1998).

RESULTS:

Water Quality Evaluation and Analysis

In accordance with the Project Management Plan, Section (3)(d) 1 of the Lake Okeechobee Protection Program, this section presents the baseline results of constituent concentrations. Approximately 14,000 water quality samples were available for analysis from the District in-lake monitoring stations. Monthly mean values for TP and OPO4 and the associated 12-month averages were plotted in time series graphs and notched box and whisker plots for each ecological region (see **Appendices B** and **C**).

Results of the notched and whisker plots analysis indicated the following:

A general comparison of the notched box-and-whisker plots showed an increase in TP and OPO4 in all the stations; however, it was more evident at the Long Term Pelagic (LTP), Fisheating Bay (FEB), and South Littoral (SL) regions. Based on the limited number of sampling events in FEB, SL, and North Littoral (NL) regions, significant statistical differences among the regions over time could not be determined. These monitoring stations have been sampled only since 1996. The notches about the medians did not display significant differences in TP. Higher variability in the data set around the median was observed for OPO4 in some years. Lake stages may be responsible for some of the variability of these data. During the years 2000 and 2001, the lake experienced drought conditions that dropped the lake stage in June 2001 below 9 ft., a record low. Due to the dry conditions, limited sampling was conducted in FEB and the other littoral regions. The North Near Shore (NNS), and South Near Shore (SNS) had a longer period of records (1986–2001). The results of the notched box-and-whisker plots did not establish a statistically significant trend at these stations (**Appendix B**). The use of the median as a measure of central tendency did not elucidate if a significant trend is present at the regional level, therefore, it is more appropriate to use the monthly means, the minimum, the maximum (Table 3, **Appendix A**) as the measure of central tendency, as shown in the time series graphs (**Appendix C**). A regression line was added to the graphs to show the general data trend, the dashed lines are 95% confidence boundaries. A clear datum on the time series graph represents a non-computed value in the regression line. These data were excluded from the calculation of the r^2 to avoid any skewed results caused by the limited amount of samples and their high concentration values.

Results of the Kendall's Tau Test and time series analysis indicated the following:

In the pelagic region, represented by stations L001 to L008, the Kendall's Tau analyses showed a rising trend in phosphorus and ortho-phosphorus with an associated probability value $p\alpha 0.000$ for TP, and $p\alpha 0.001$ for OPO4. The pelagic region has been sampled by the District since 1973, and it is well documented that total phosphorus concentrations have more than doubled since the early 1970's (James et al., 1995a). The high concentrations reflect a long history of excessive phosphorus inputs to the system (James et al., 1995b) by human activities in the watershed, in particular agricultural activities. The notched box-and-whisker plots and the time series graphs also suggest how the two parameters are affected by lake stages and seasonal variations. Re-suspension and transportation of phosphorus-rich mud sediments from the mid-lake towards the shoreline areas are wind and current driven, especially during times of high lake levels (Maceina,1993). The statistical results of this analysis confirmed previous similar studies documenting the increase of phosphorus and ortho-phosphorus during the 30-year period of record.

The region FEB is represented by stations FEBIN and FEBOUT. The range of pooled monthly mean concentrations for TP varies from 0.04 mg/L to 0.156 mg/L, and from 0.03 mg/L to 0.11 mg/L for OPO4. An increasing trend in both parameters seems to occur, however, from 8/21/00 to 10/15/01, only four samples were collected due to the dry conditions and the lake's low stage level. Higher phosphorus concentrations were expected in the October 2001 samples as the lake stage increased between August–September 2001, reaching over 14.5 ft. on October 25, 2001. The higher phosphorus levels at this time can been attributed to an increase of water inputs from Fisheating Creek, and from transport of water and re-suspended sediment materials when water levels in the lake are high (Havens et al., 2000).

The seasonal Kendall's Tau test was applied to determine the presence of increasing or decreasing significant trends at individual stations. A significant rising trend for TP and OPO4 was found at the LTP stations. (Table 5 and 6, **Appendix A**). On a regional basis, the Kendall's Tau indicated statistically significant increasing trends in TP concentrations at FEB, LTP, and NL (Table 4, **Appendix A**). In the FEB region, there was a significant increasing trend in phosphorus with a significant associated probability value of $p\alpha 0.002$ for the time period 1996–2001. Due to the dramatic change in stage in 2001 and to the limited range of data, this result should be viewed with caution. Future analyses will look at a broader data set to establish with certainty the magnitude of the observed trend.

A similarly conservative approach was considered in analyzing the statistics of the NL region. The north littoral region includes stations TIN13700, TIN16100, and TIN8100. These stations have been sampled since 1996; only 258 total samples were available for analyses. The range of pooled monthly mean concentrations for TP varies from 0.032 mg/L to 0.07 mg/L, and from 0.017 mg/L to 0.015 mg/L for OPO4. The increasing trend is observed for TP only. In these stations only three samples per each parameter were collected (from 8/21/00 to 10/15/01) due to the drought conditions. The NL region has been generally characterized with relatively low levels of TP in the five-year period of sampling. As stated earlier, this region receives most of its phosphorus inputs from rainfall when water levels in the lake are low, and may receive inputs of phosphorus from the pelagic region when water levels are high (Steinman et al., 1998). During the drought, many areas of the littoral zones grew a dense population of herbaceous, terrestrial vegetation. Following the lake stage increase and the rainfall increase between August–October 2001, this vegetation began to die as the areas were reinundated, presumably releasing phosphorus nutrients to the water column. Remineralization and subsequent resuspension of phosphorus-rich sediments appears also to have increased concentrations in this region. The Kendall's Tau test indicated a statistically significant increasing trend in TP concentrations with an associated probability value $p\alpha 0.002$; however, a longer period of record is necessary to support the significance of these findings.

No statistically significant p values were observed for trends in TP or OPO4 in the NNS region. Statistically significant p values were observed for the 3RDPTOUT, KBAROUT, POLESOUT, and STAKEOUT. This region has a range of pooled monthly mean concentrations for TP from 0.232 mg/L to 0.089 mg/L, and from 0.131 mg/L to 0.028 mg/L for OPO4. The temporal trend analysis observed in the graphs showed an increase in TP but not for OPO4, where the trend was very linear and showed little or no seasonality. It must be noted that the calculated value $p\alpha 0.054$ in Table 4 is an adjusted p value for significant serially correlated data. The statistical analyses of this particular region did not indicate if an apparent long trend is present. Additional sampling and a longer period of record may at some point confirm the trend.

The SL ecological region is represented by stations MBOXSOU, MH12000, MH16000, MH24000, MH32000. The range of pooled monthly mean concentrations for TP varies from 0.006 mg/L to 0.349 mg/L, and from 0.002 mg/L to 0.293 mg/L for OPO4. An increasing trend in both parameters seems to occur, however, only four samples were collected in 2001 due to the dry conditions and the lake's low stage level. Here, also, higher phosphorus concentrations were expected for that year for the reasons previously discussed in earlier paragraphs. It is important to emphasize that up to August 2000, yearly data in this littoral region showed very low levels of TP and OPO4. Phosphorus inputs are attributed to rainfall and inputs from phosphorus-rich dead plants material. The Kendall's Tau value of $p\alpha 0.110$ confirms that no significant trends were observed in this marsh area.

The SNS region also did not indicate any significant trends. The time series analysis shows a negligible increase for TP ranging from 0.057 mg/L to 0.068 mg/L. A slight decline in concentrations was also observed for OPO4 ranging from 0.016 mg/L to 0.011 mg/L. The Kendall's Tau statistic was not significant for TP or OPO4. Variability within the data set follows seasonal patterns and water levels in the lake.

ANALYSIS OF COVARIANCE FOR THE LAKE REGIONS

Total Phosphorus

For the purpose of this analysis it is emphasized that the data were log transformed and displayed as adjusted geomeans. The ANOCOVA indicated that the pelagic region is statistically higher in TP concentration from all the other regions, with a significant associated probability value of $p\alpha 0.001$ (**Table 1b**). The FEB region was observed to be significantly different only from NNS and SL. The NL region was significantly different from NNS and SNS. Statistically significant differences were also observed between NNS and the other two littoral regions: SL and SNS; while SL was significantly different from SNS.

Table 1b. ANOCOVA for TP for the Lake Regions

FEB		0.0012	0.9915	0.0382	<.0001	1	0.024954128
LTP	0.0012		<.0001	<.0001	<.0001	<.0001	0.086179078
NL	0.9915	<.0001		<.0001	0.0604	<.0001	0.011816466
NNS	0.0382	<.0001	<.0001		<.0001	<.0001	0.064456086
SL	<.0001	<.0001	0.0604	<.0001		<.0001	0.004500693
SNS	1	<.0001	<.0001	<.0001	<.0001		0.044131921

Notes: Values <0.05 indicate a significant difference in TP concentration between the regions
Number in shaded cells represents a placeholder value not computed in the statistics.

Ortho-phosphorus

The ANOCOVA indicated that the pelagic region is significantly higher in OPO4 concentrations from all the other regions except FEB. The FEB region is not significantly different from any of the other ecological regions (**Table 1c**). The NNS region is significantly different only from SL and SNS, while SL region is significantly different from SNS.

Table 1c. ANOCOVA for OPO4 for the Lake Regions

FEB		0.0785	1	0.8043	0.7605	1	0.002677407
LTP	0.0785		<.0001	<.0001	<.0001	<.0001	0.016303301
NL	1	<.0001		0.0031	1	0.0799	0.001198245
NNS	0.8043	<.0001	0.0031		<.0001	<.0001	0.009358307
SL	0.7605	<.0001	1	<.0001		<.0001	0.000578795
SNS	1	<.0001	0.0799	<.0001	<.0001		0.005597016

Notes: Values <0.05 indicate a significant difference in OPO4 concentration between the regions
Number in shaded cells represents a placeholder value not computed in the statistics

Results of this analysis at the regional level indicate a significant increasing trend for TP and OPO4 at the pelagic region, and confirm the previous statistical analysis and trends so far observed in this area. The rest of the lake regions showed significant differences among each other, differences not previously observed with the Kendall's Tau test. However, an in-depth analysis between the monitoring stations, which is beyond the scope of this baseline, is recommended for further delineation of these ecological boundaries. The comparison of the findings at station level could elucidate a possible future reassessment of the monitoring stations closer to the internal interactions and dynamics of Lake Okeechobee.

CONCLUSIONS

The summary statistic presented for the lake regions (**Table 1a**) and the individual stations (Table 3, **Appendix A**), indicate that TP and OPO4 data are highly variable. The standard deviation is often equal to or greater than the mean. This is also observed in the data plots (**Appendix C**), showing seasonal and annual variability. However, comparison of ecological regions by the ranking of the means and the medians values, revealed that the SL region has the lowest TP and OPO4 concentrations, followed by NL and SNS. The last three regions, NNS, LTP and FEB, had the highest concentrations, with Fisheating Bay displaying the highest value. The additional baseline data presented in this report shows significant water quality changes in the pelagic region over the 30 years period of record. The seasonal Kendall's Tau test found a strong evidence of a linear increasing trend for TP and OPO4 in this ecological region (Table 4, **Appendix A**). Although there is some evidence of a linear increasing trend in TP for the North Littoral Region and Fisheating Bay, there are not sufficient data to support the determination of statistically significant trends in total concentrations about these regions. A longer period of record is necessary in order to support the significance of these findings. Results of the ANOCOVA **(Tables 1b, 1c)** indicated that at regional level, a significant trend for TP and OPO4 is observed at the pelagic region. This confirms the previous statistical analysis and trends observed thus far in this area. The rest of the ecological regions showed significant differences among each other, differences not previously observed with the non-parametric Kendall's Tau test. The results of this baseline support the need to continue sampling at these monitoring stations.

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APPENDIX A

Table 1. Water Quality Monitoring Stations for TP and OPO4

STATION ID	Min Of DATE	Max Of DATE	Number of TP	Number of PO4	Total Samples	LAKE REGIONS
FEBIN	17-Jan-96	15-Oct-01	51	51	102	Fisheating Bay(FEB)
FEBOUT	17-Jan-96	15-Oct-01	42	41	83	Fisheating Bay(FEB)
L001	11-Dec-72	15-Oct-01	502	506	1008	Long Term Pelagic(LTP)
L002	6-Nov-72	15-Oct-01	489	477	966	Long Term Pelagic(LTP)
L003	11-Dec-72	15-Oct-01	463	467	930	Long Term Pelagic(LTP)
L004	6-Nov-72	15-Oct-01	473	473	946	Long Term Pelagic(LTP)
L005	6-Nov-72	15-Oct-01	478	481	959	Long Term Pelagic(LTP)
L006	6-Nov-72	16-Oct-01	491	495	986	Long Term Pelagic(LTP)
L007	6-Nov-72	16-Oct-01	474	477	951	Long Term Pelagic(LTP)
L008	12-Dec-72	15-Oct-01	457	458	915	Long Term Pelagic(LTP)
TIN13700	17-Jan-96	15-Oct-01	41	41	82	North Littoral(NL)
TIN16100	17-Jan-96	15-Oct-01	47	47	94	North Littoral(NL)
TIN8100	17-Jan-96	15-Oct-01	41	41	82	North Littoral(NL)
3RDPTOUT	17-Nov-86	15-Oct-01	235	234	469	North near Shore(NNS)
KBAROUT	29-Jul-86	6-Jun-00	231	230	461	North near Shore(NNS)
KISSR0.0	29-Jul-86	15-Oct-01	261	259	520	North near Shore(NNS)
POLESOUT	27-Jun-88	15-Oct-01	202	200	402	North near Shore(NNS)
STAKEOUT	17-Nov-86	15-Oct-01	228	225	453	North near Shore(NNS)
MBOXSOU	13-Feb-96	15-Oct-01	40	40	80	South Littoral(SL)
MH12000	17-Jan-96	1-May-00	38	38	76	South Littoral(SL)
MH16000	17-Jan-96	15-Oct-01	40	40	80	South Littoral(SL)
MH24000	17-Jan-96	15-Oct-01	43	43	86	South Littoral(SL)
MH32000	17-Jan-96	15-Oct-01	47	47	94	South Littoral(SL)
PALMOUT	17-Nov-86	16-Oct-01	221	220	441	South near shore(SNS)
PELMID	23-Jun-86	16-Oct-01	255	256	511	South near shore(SNS)
PLN2OUT	28-Jun-88	16-Oct-01	192	191	383	South near shore(SNS)
POLE3S	13-Jun-94	16-Oct-01	115	115	230	South near shore(SNS)
RITAEAST	10-Jul-86	16-Oct-01	249	250	499	South near shore(SNS)
RITAWEST	10-Jul-86	16-Oct-01	244	244	488	South near shore(SNS)
TREEOUT	17-Nov-86	16-Oct-01	223	223	446	South near shore(SNS)

Table 3. Summary Statistics for TP and OPO4 in-Lake Monitoring Stations

STATION ID	TEST NAME	n	mean	std dev.	median	min	max	Lake Region
FEBIN	OPO4	46	0.0513	0.0596	0.0205	0.002	0.237	Fisheating Bay
FEBIN	TP	46	0.1292	0.0984	0.116	0.031	0.613	Fisheating Bay
FEBOUT	OPO4	37	0.0192	0.0249	0.007	0.002	0.091	Fisheating Bay
FEBOUT	TP	36	0.0909	0.0441	0.078	0.018	0.176	Fisheating Bay
L001	OPO4	314	0.0203	0.0196	0.0136	0.001	0.09	Long Term Pelagic
L001	TP	316	0.0863	0.0384	0.07925	0.0203	0.277	Long Term Pelagic
L002	OPO4	320	0.0189	0.0193	0.011	0.001	0.104	Long Term Pelagic
L002	TP	320	0.0819	0.0401	0.074	0.01	0.297	Long Term Pelagic
L003	OPO4	318	0.0275	0.0192	0.0255	0.001	0.077	Long Term Pelagic
L003	TP	319	0.1005	0.0485	0.093	0.026	0.329	Long Term Pelagic
L004	OPO4	317	0.0307	0.0187	0.03	0.001	0.083	Long Term Pelagic
L004	TP	319	0.1056	0.0472	0.099	0.0195	0.266	Long Term Pelagic
L005	OPO4	319	0.0128	0.0198	0.004	0.001	0.123	Long Term Pelagic
L005	TP	317	0.0644	0.0410	0.0539	0.01	0.2745	Long Term Pelagic
L006	OPO4	323	0.0334	0.0196	0.032	0.0008	0.099	Long Term Pelagic
L006	TP	324	0.0971	0.0439	0.091	0.017	0.2545	Long Term Pelagic
L007	OPO4	315	0.0261	0.0212	0.022	0.001	0.088	Long Term Pelagic
L007	TP	316	0.0784	0.0380	0.07215	0.012	0.212	Long Term Pelagic
L008	OPO4	313	0.0232	0.0210	0.0177	0.001	0.097	Long Term Pelagic
L008	TP	314	0.1006	0.0524	0.08775	0.017	0.295	Long Term Pelagic
TIN13700	OPO4	39	0.0157	0.0123	0.014	0.002	0.05	North Littoral
TIN13700	TP	40	0.0655	0.0447	0.0575	0.011	0.207	North Littoral
TIN16100	OPO4	42	0.0133	0.0159	0.007	0.002	0.07	North Littoral
TIN16100	TP	41	0.0927	0.0406	0.0805	0.037	0.18	North Littoral
TIN8100	OPO4	36	0.0050	0.0026	0.005	0.002	0.014	North Littoral
TIN8100	TP	36	0.0186	0.0196	0.012	0.004	0.109	North Littoral
3RDPTOUT	OPO4	159	0.0119	0.0142	0.006	0.002	0.076	North near Shore
3RDPTOUT	TP	161	0.0681	0.0353	0.0575	0.013	0.221	North near Shore
KBAROUT	OPO4	155	0.0247	0.0275	0.016	0.002	0.162	North near Shore
KBAROUT	TP	157	0.0871	0.0405	0.077	0.026	0.298	North near Shore
KISSR0.0	OPO4	168	0.0378	0.0383	0.02615	0.002	0.18	North near Shore
KISSR0.0	TP	171	0.1001	0.0484	0.085	0.036	0.3225	North near Shore
POLESOUT	OPO4	139	0.0101	0.0125	0.005	0.002	0.074	North near Shore
POLESOUT	TP	142	0.0678	0.0334	0.05775	0.022	0.184	North near Shore
STAKEOUT	OPO4	153	0.0113	0.0134	0.006	0.002	0.071	North near Shore
STAKEOUT	TP	157	0.0703	0.0357	0.063	0.019	0.222	North near Shore
MBOXSOU	OPO4	36	0.0339	0.1413	0.008	0.002	0.855	South Littoral
MBOXSOU	TP	35	0.0507	0.1549	0.021	0.008	0.935	South Littoral
MH12000	OPO4	32	0.0043	0.0024	0.004	0.002	0.01	South Littoral
MH12000	TP	31	0.0120	0.0076	0.01	0.002	0.037	South Littoral
MH16000	OPO4	35	0.0042	0.0023	0.004	0.002	0.009	South Littoral
MH16000	TP	34	0.0121	0.0050	0.0115	0.004	0.023	South Littoral
MH24000	OPO4	39	0.0042	0.0023	0.004	0.002	0.01	South Littoral
MH24000	TP	37	0.0161	0.0171	0.013	0.005	0.109	South Littoral
MH32000	OPO4	43	0.0130	0.0454	0.004	0.002	0.299	South Littoral
MH32000	TP	41	0.0320	0.0609	0.02	0.009	0.405	South Littoral
PALMOUT	OPO4	144	0.0094	0.0141	0.004	0.001	0.069	South near Shore
PALMOUT	TP	146	0.0524	0.0383	0.038	0.002	0.214	South near Shore
PELMID	OPO4	169	0.0251	0.0213	0.019	0.002	0.113	South near Shore
PELMID	TP	171	0.0840	0.0373	0.078	0.023	0.305	South near Shore
PLN2OUT	OPO4	131	0.0090	0.0138	0.004	0.0017	0.071	South near Shore
PLN2OUT	TP	134	0.0537	0.0443	0.035	0.01	0.251	South near Shore
POLE3S	OPO4	77	0.0211	0.0228	0.008	0.002	0.084	South near Shore
POLE3S	TP	79	0.0761	0.0452	0.064	0.018	0.195	South near Shore
RITAEAST	OPO4	167	0.0095	0.0156	0.004	0.002	0.085	South near Shore
RITAEAST	TP	169	0.0504	0.0361	0.043	0.002	0.179	South near Shore
RITAWEST	OPO4	163	0.0127	0.0210	0.005	0.002	0.129	South near Shore
RITAWEST	TP	165	0.0606	0.0406	0.051	0.004	0.2	South near Shore
TREEOUT	OPO4	147	0.0110	0.0157	0.005	0.002	0.095	South near Shore
TREEOUT	TP	149	0.0596	0.0411	0.046	0.014	0.228	South near Shore

Table 4. Seasonal Kendall's Tau Slope Statistic for TP and OPO4 by Lake Regions

LAKE REGIONS	1972-1982		1983-1992		1993-2001		1972-2001		Min Of DATE	Max Of DATE
Parameter OPO4	Slope	P value	Slope	P value	Slope	P value	Slope	P value		
Fisheating Bay (FEB)	N/A	N/A	N/A	N/A	0.000	0.853	0.000	0.853	17-Jan-96	15-Oct-01
Long Term Pelagic (LTP)	0.002	**0.007**	0.000	**0.665**	0.001	**0.134**	0.001	**0.001**	6-Nov-72	16-Oct-01
North Littoral (NL)	N/A	N/A	N/A	N/A	0.002	**0.114**	0.002	**0.114**	17-Jan-96	15-Oct-01
North near Shore (NNS)	N/A	N/A	0.000	0.685	0.001	**0.431**	0	**0.913**	29-Jul-86	15-Oct-01
South Littoral (SL)	N/A	N/A	N/A	N/A	0.001	0.016	0.001	0.016	17-Jan-96	15-Oct-01
South near Shore (SNS)	N/A	N/A	-0.001	**0.231**	0.000	**0.353**	0.000	**0.392**	23-Jun-86	16-Oct-01

LAKE REGIONS	1972-1982		1983-1992		1993-2001		1972-2001		Min Of DATE	Max Of DATE
Parameter TP	Slope	P value	Slope	P value	Slope	P value	Slope	P value		
Fisheating Bay (FEB)	N/A	N/A	N/A	N/A	0.017	**0.002**	0.017	0.002	17-Jan-96	15-Oct-01
Long Term Pelagic (LTP)	0.004	0	-0.001	**0.438**	0.005	**0.016**	0.002	**0.000**	6-Nov-72	16-Oct-01
North Littoral (NL)	N/A	N/A	N/A	N/A	0.007	**0.002**	0.007	0.002	17-Jan-96	15-Oct-01
North near Shore (NNS)	N/A	N/A	-0.003	**0.018**	0.005	**0.011**	0.001	**0.054**	29-Jul-86	15-Oct-01
South Littoral (SL)	N/A	N/A	N/A	N/A	0.001	**0.110**	0.001	**0.110**	17-Jan-96	15-Oct-01
South near Shore (SNS)	N/A	N/A	-0.004	**0.104**	0.001	**0.816**	0.001	**0.334**	23-Jun-86	16-Oct-01

N/A= Data not available

Note: The P values in bold have been adjusted for significant serially correlated data, the other associated P values are not serially correlated data

Shaded cells represent a significant P value <0.05

Table 5. Seasonal Kendall's Tau Slope Statistic for TP by Station

STATION ID	1972-1982		1983-1992		1993-2001		1972-2001		Min Of DATE	Max Of DATE	LAKE REGIONS
Parameter TP	Slope	P value	Slope	P value	Slope	P value	Slope	P value			
FEBIN	N/A	N/A	N/A	N/A	0.021	0.005	0.021	0.005	17-Jan-96	15-Oct-01	Fisheating Bay(FEB)
FEBOUT	N/A	N/A	N/A	N/A	0.016	0.386	0.016	0.386	17-Jan-96	15-Oct-01	Fisheating Bay(FEB)
L001	0.004	0.056	-0.001	0.420	0.007	0.000	0.001	0.000	11-Dec-72	15-Oct-01	Long Term Pelagic(LTP)
L002	0.003	0.000	0.000	0.761	0.005	0.000	0.001	0.000	6-Nov-72	15-Oct-01	Long Term Pelagic(LTP)
L003	0.004	0.000	0.000	0.889	0.006	0.000	0.002	0.000	11-Dec-72	15-Oct-01	Long Term Pelagic(LTP)
L004	0.004	0.000	-0.001	0.763	0.004	0.001	0.002	0.000	6-Nov-72	15-Oct-01	Long Term Pelagic(LTP)
L005	0.004	0.000	-0.001	0.312	0.003	0.141	0.001	0.000	6-Nov-72	15-Oct-01	Long Term Pelagic(LTP)
L006	0.004	0.000	-0.001	0.360	0.001	0.459	0.002	0.000	6-Nov-72	16-Oct-01	Long Term Pelagic(LTP)
L007	0.004	0.000	-0.001	0.289	0.003	0.242	0.002	0.000	6-Nov-72	16-Oct-01	Long Term Pelagic(LTP)
L008	0.003	0.001	-0.001	0.243	0.007	0.000	0.002	0.000	12-Dec-72	15-Oct-01	Long Term Pelagic(LTP)
TIN13700	N/A	N/A	N/A	N/A	0.019	0.000	0.019	0.000	17-Jan-96	15-Oct-01	North Littoral(NL)
TIN16100	N/A	N/A	N/A	N/A	-0.001	0.918	-0.001	0.918	17-Jan-96	15-Oct-01	North Littoral(NL)
TIN8100	N/A	N/A	N/A	N/A	0.002	0.191	0.002	0.191	17-Jan-96	15-Oct-01	North Littoral(NL)
3RDPTOUT	N/A	N/A	0.554	0.155	0.005	0.025	0.002	0.023	17-Nov-86	15-Oct-01	North near Shore(NNS)
KBAROUT	N/A	N/A	-0.002	0.317	0.005	0.025	0.002	0.028	29-Jul-86	15-Oct-01	North near Shore(NNS)
KISSR0.0	N/A	N/A	0.000	0.835	0.004	0.002	0.001	0.448	29-Jul-86	15-Oct-01	North near Shore(NNS)
POLESOUT	N/A	N/A	-0.001	0.554	0.005	0.025	0.003	0.004	27-Jun-88	15-Oct-01	North near Shore(NNS)
STAKEOUT	N/A	N/A	-0.005	0.105	0.005	0.063	0.002	0.001	17-Nov-86	15-Oct-01	North near Shore(NNS)
MBOXSOU	N/A	N/A	N/A	N/A	0.004	0.179	0.004	0.179	13-Feb-96	15-Oct-01	South Littoral(SL)
MH12000	N/A	N/A	N/A	N/A	0.002	0.170	0.002	0.170	17-Jan-96	15-Oct-01	South Littoral(SL)
MH16000	N/A	N/A	N/A	N/A	0.002	0.002	0.002	0.002	17-Jan-96	15-Oct-01	South Littoral(SL)
MH24000	N/A	N/A	N/A	N/A	0.001	0.232	0.001	0.232	17-Jan-96	15-Oct-01	South Littoral(SL)
MH32000	N/A	N/A	N/A	N/A	0.002	0.270	0.002	0.270	17-Jan-96	15-Oct-01	South Littoral(SL)
PALMOUT	N/A	N/A	-0.005	0.124	0.005	0.066	0.002	0.095	17-Nov-86	16-Oct-01	South near shore(SNS)
PELMID	N/A	N/A	-0.004	0.068	0.001	0.917	0.001	0.344	23-Jun-86	16-Oct-01	South near shore(SNS)
PLN2OUT	N/A	N/A	-0.006	0.136	0.001	0.614	0.002	0.080	28-Jun-88	16-Oct-01	South near shore(SNS)
POLE3S	N/A	N/A	N/A	N/A	0.000	0.939	0.000	0.939	13-Jun-94	16-Oct-01	South near shore(SNS)
RITAEAST	N/A	N/A	-0.003	0.003	0.001	0.564	0.001	0.487	10-Jul-86	16-Oct-01	South near shore(SNS)
RITAWEST	N/A	N/A	-0.003	0.049	0.001	0.696	0.002	0.111	10-Jul-86	16-Oct-01	South near shore(SNS)
TREEOUT	N/A	N/A	-0.006	0.125	0.005	0.118	0.002	0.149	17-Nov-86	16-Oct-01	South near shore(SNS)

N/A= Data not available

Note: The P values in bold have been adjusted for significant serially correlated data, the other associated P values are not serially correlated data
Shaded cells represent a significant P value <0.05

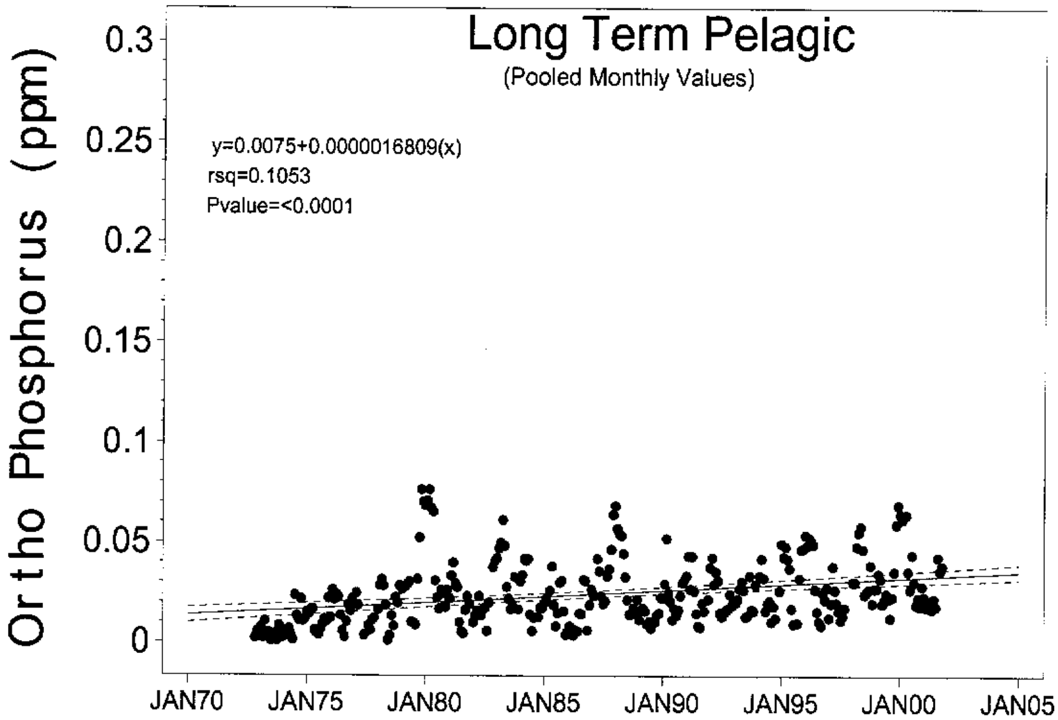
Table 6. Seasonal Kendall's Tau Slope Statistic for OPO4 by Station

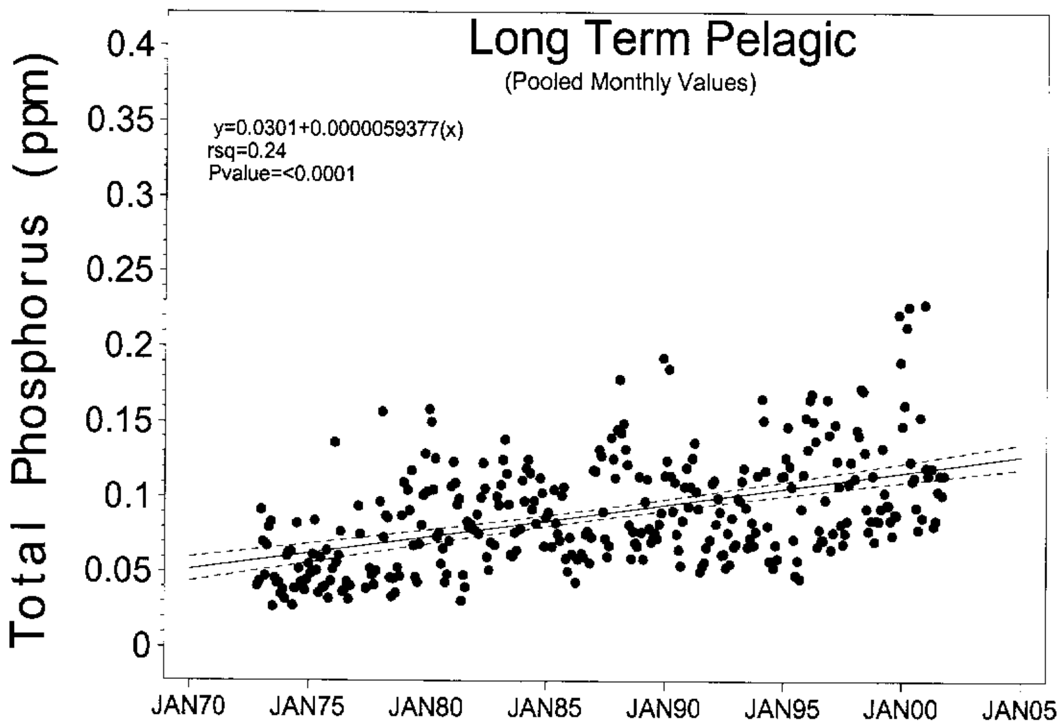
STATION ID	1972-1982		1983-1992		1993-2001		1972-2001		Min Of DATE	Max Of DATE	LAKE REGIONS
Parameter OPO4	Slope	P value	Slope	P value	Slope	P value	Slope	P value			
FEBIN	N/A	N/A	N/A	N/A	0.000	1	0.000	1	17-Jan-96	15-Oct-01	Fisheating Bay(FEB)
FEBOUT	N/A	N/A	N/A	N/A	0.002	**0.197**	0.002	**0.197**	17-Jan-96	15-Oct-01	Fisheating Bay(FEB)
L001	0.001	**0.013**	0.000	**0.589**	0.001	**0.240**	0.000	**0.001**	11-Dec-72	15-Oct-01	Long Term Pelagic(LTP)
L002	0.001	**0.084**	0	**0.806**	0.001	**0.339**	0.000	**0.005**	6-Nov-72	15-Oct-01	Long Term Pelagic(LTP)
L003	0.003	**0.013**	0	**0.910**	0.002	**0.246**	0.001	**0.002**	11-Dec-72	15-Oct-01	Long Term Pelagic(LTP)
L004	0.004	**0.007**	0.000	**0.740**	0.002	**0.167**	0.001	**0.001**	6-Nov-72	15-Oct-01	Long Term Pelagic(LTP)
L005	0.000	**0.094**	0	**0.637**	0.001	**0.121**	0.000	**0.000**	6-Nov-72	15-Oct-01	Long Term Pelagic(LTP)
L006	0.003	**0.010**	-0.001	**0.306**	0.001	**0.162**	0.001	**0.000**	6-Nov-72	16-Oct-01	Long Term Pelagic(LTP)
L007	0.002	**0.057**	-0.001	**0.163**	0.003	**0.039**	0.001	**0.005**	6-Nov-72	16-Oct-01	Long Term Pelagic(LTP)
L008	0.001	**0.048**	-0.001	**0.564**	0.002	0.003	0.001	**0.000**	12-Dec-72	15-Oct-01	Long Term Pelagic(LTP)
TIN13700	N/A	N/A	N/A	N/A	0.005	**0.000**	0.005	0.000	17-Jan-96	15-Oct-01	North Littoral(NL)
TIN16100	N/A	N/A	N/A	N/A	0.001	**0.501**	0.001	**0.501**	17-Jan-96	15-Oct-01	North Littoral(NL)
TIN8100	N/A	N/A	N/A	N/A	0.001	**0.498**	0.001	**0.498**	17-Jan-96	15-Oct-01	North Littoral(NL)
3RDPTOUT	N/A	N/A	0.000	**0.246**	0.000	**0.163**	0	**0.265**	17-Nov-86	15-Oct-01	North near Shore(NNS)
KBAROUT	N/A	N/A	0.000	0.874	0.000	**0.163**	0.000	**0.709**	29-Jul-86	15-Oct-01	North near Shore(NNS)
KISSR0.0	N/A	N/A	0.002	0.395	0	1	0.000	**0.663**	29-Jul-86	15-Oct-01	North near Shore(NNS)
POLESOUT	N/A	N/A	0	0.327	0.001	**0.205**	0.000	**0.055**	27-Jun-88	15-Oct-01	North near Shore(NNS)
STAKEOUT	N/A	N/A	0	**0.578**	0.001	**0.226**	0	**0.667**	17-Nov-86	15-Oct-01	North near Shore(NNS)
MBOXSOU	N/A	N/A	N/A	N/A	0.002	**0.384**	0.002	**0.384**	13-Feb-96	15-Oct-01	South Littoral(SL)
MH12000	N/A	N/A	N/A	N/A	0.001	**0.034**	0.001	**0.034**	17-Jan-96	15-Oct-01	South Littoral(SL)
MH16000	N/A	N/A	N/A	N/A	0.001	0.048	0.001	0.048	17-Jan-96	15-Oct-01	South Littoral(SL)
MH24000	N/A	N/A	N/A	N/A	0.001	0.014	0.001	0.014	17-Jan-96	15-Oct-01	South Littoral(SL)
MH32000	N/A	N/A	N/A	N/A	0.001	0.036	0.001	0.036	17-Jan-96	15-Oct-01	South Littoral(SL)
PALMOUT	N/A	N/A	0.000	**0.346**	0.001	**0.065**	0	**0.290**	17-Nov-86	16-Oct-01	South near shore(SNS)
PELMID	N/A	N/A	-0.002	0.028	0.001	**0.460**	0.000	**0.597**	23-Jun-86	16-Oct-01	South near shore(SNS)
PLN2OUT	N/A	N/A	0	**0.854**	0.000	**0.197**	0.000	**0.044**	28-Jun-88	16-Oct-01	South near shore(SNS)
POLE3S	N/A	N/A	N/A	N/A	0.001	**0.394**	0.001	**0.394**	13-Jun-94	16-Oct-01	South near shore(SNS)
RITAEAST	N/A	N/A	0	**0.668**	0.000	**0.148**	0	**0.406**	10-Jul-86	16-Oct-01	South near shore(SNS)
RITAWEST	N/A	N/A	0	0.911	0.001	**0.106**	0.000	**0.033**	10-Jul-86	16-Oct-01	South near shore(SNS)
TREEOUT	N/A	N/A	0	**0.466**	0.000	**0.192**	0	**0.650**	17-Nov-86	16-Oct-01	South near shore(SNS)

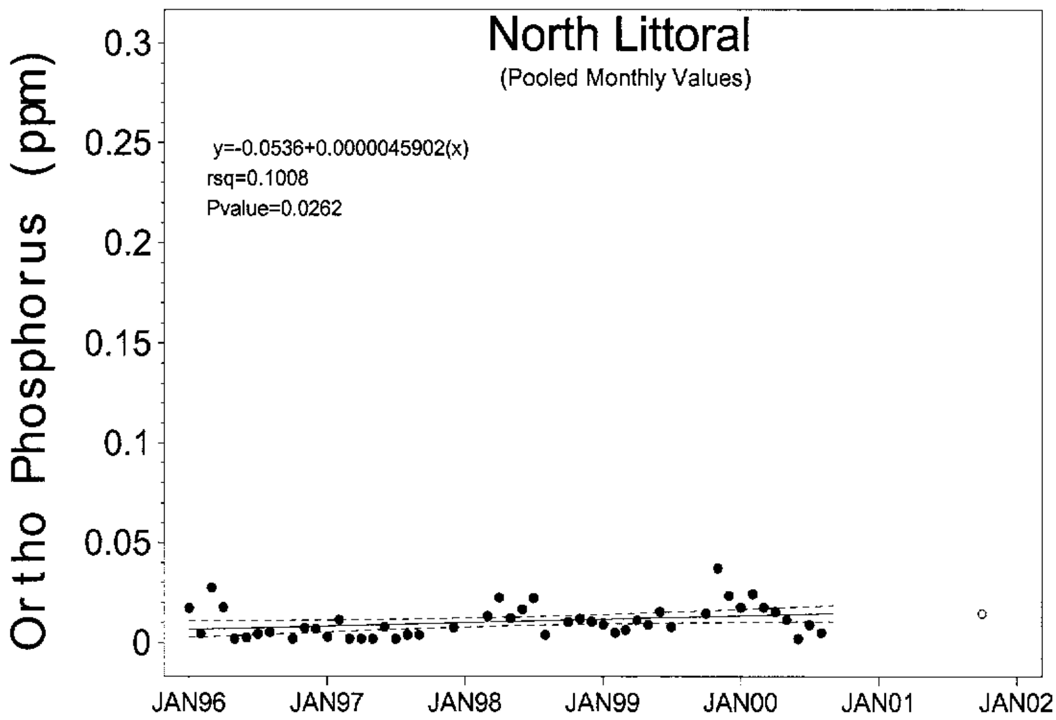
N/A= Data not available

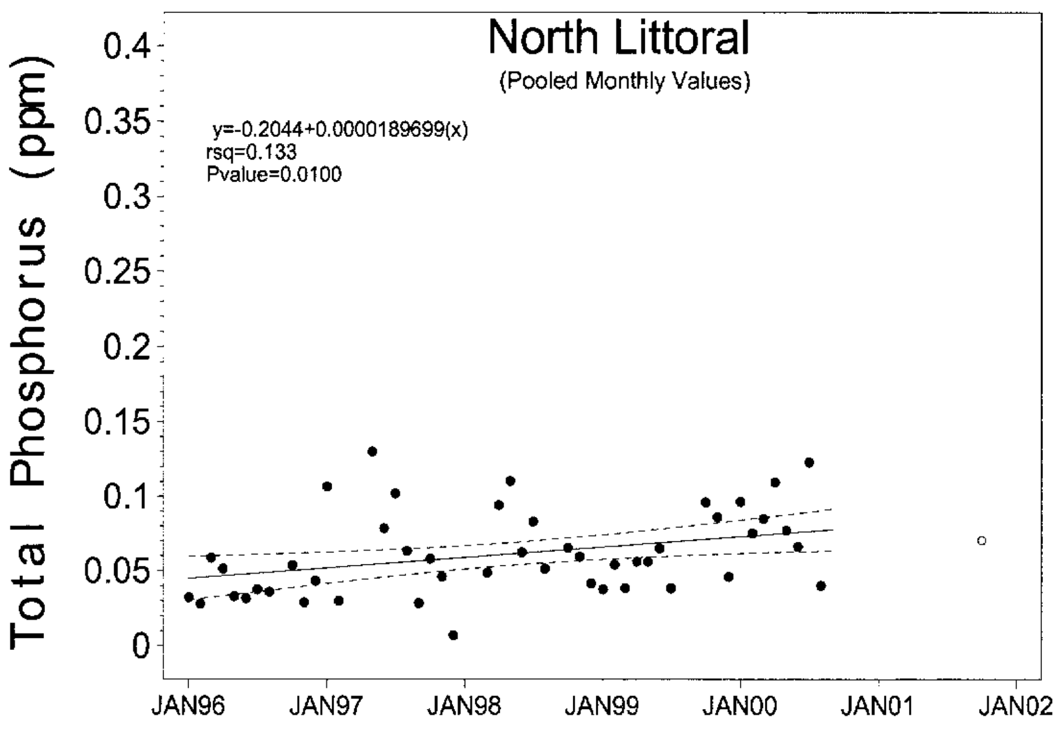
Note: The P values in bold have been adjusted for significant serially correlated data, the other associated P values are not serially correlated data
Shaded cells represent a significant P value <0.05

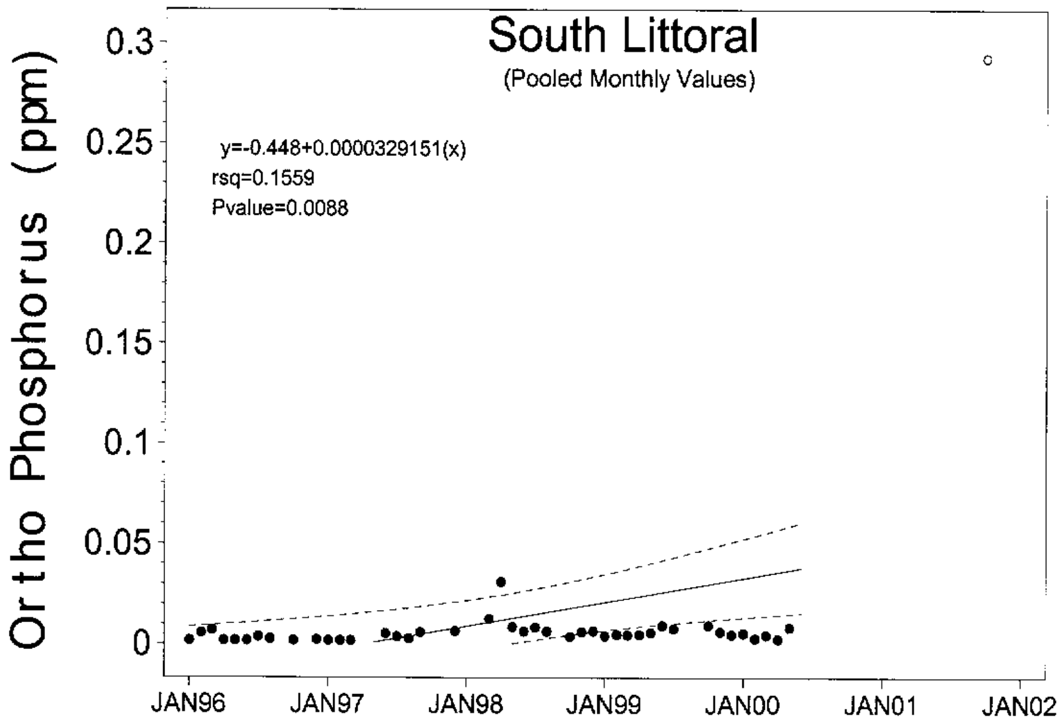
APPENDIX B


Long Term Pelagic
(Pooled Monthly Values)
y=0.0075+0.0000016809(x)
rsq=0.1053
Pvalue=<0.0001
Ortho Phosphorus (ppm)
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN70
JAN75
JAN80
JAN85
JAN90
JAN95
JAN00
JAN05

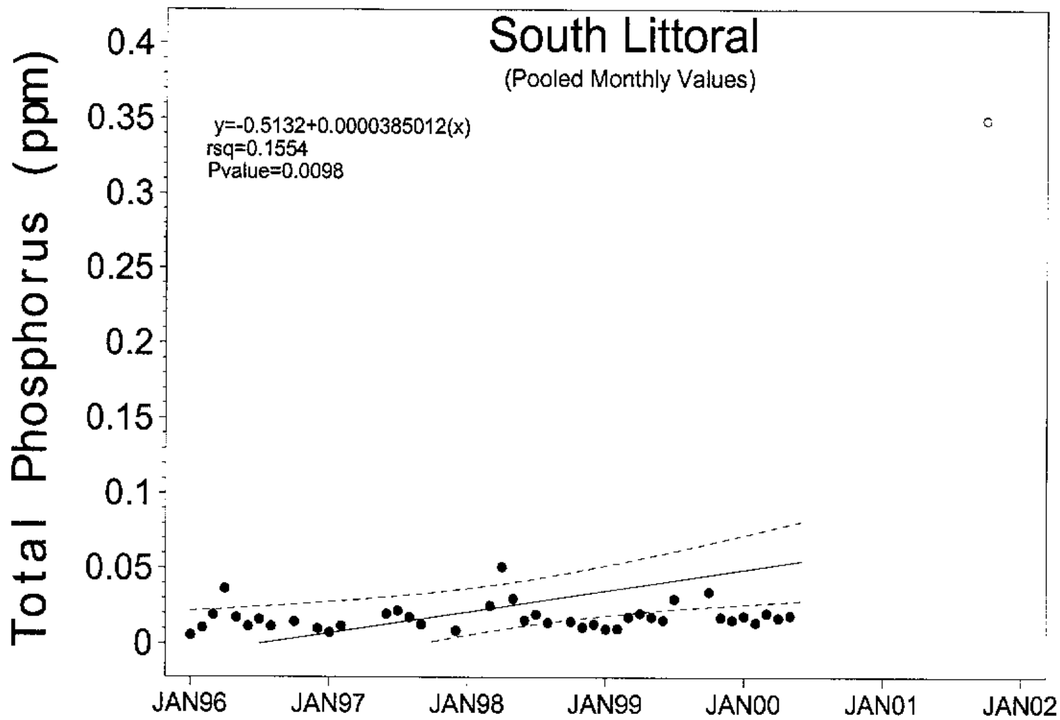

Long Term Pelagic
(Pooled Monthly Values)
y=0.0301+0.0000059377(x)
rsq=0.24
Pvalue=<0.0001
Total Phosphorus (ppm)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN70
JAN75
JAN80
JAN85
JAN90
JAN95
JAN00
JAN05


North Littoral
(Pooled Monthly Values)
y=-0.0536+0.0000045902(x)
rsq=0.1008
Pvalue=0.0262
Ortho Phosphorus (ppm)
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN96
JAN97
JAN98
JAN99
JAN00
JAN01
JAN02

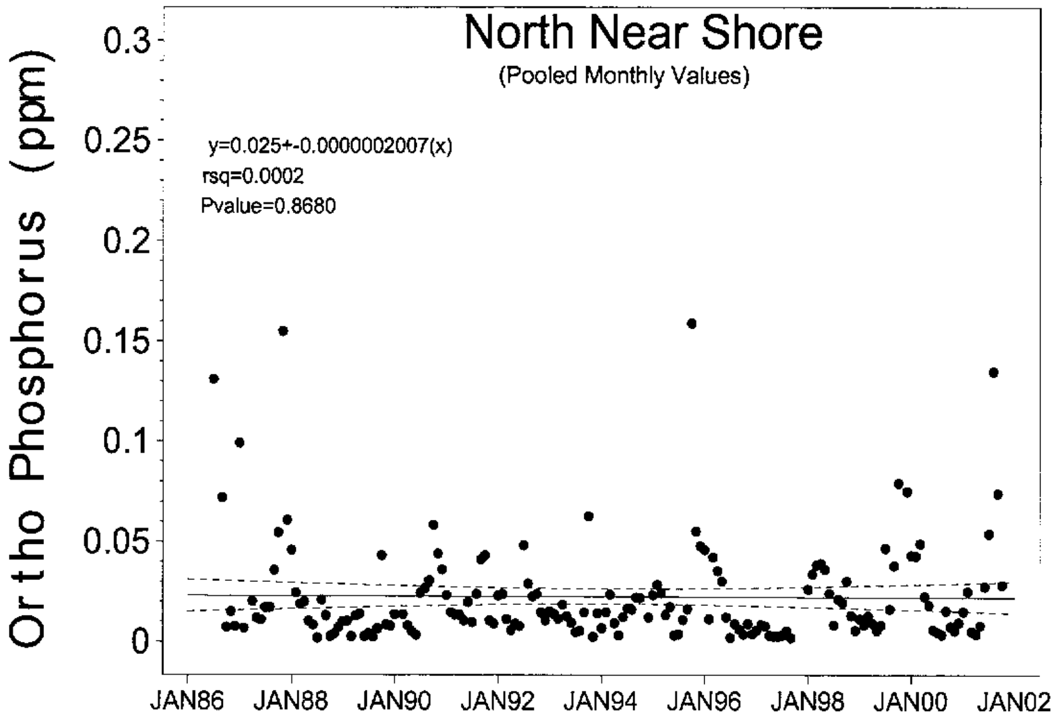

North Littoral
(Pooled Monthly Values)
y=-0.2044+0.0000189699(x)
rsq=0.133
Pvalue=0.0100
Total Phosphorus (ppm)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN96
JAN97
JAN98
JAN99
JAN00
JAN01
JAN02

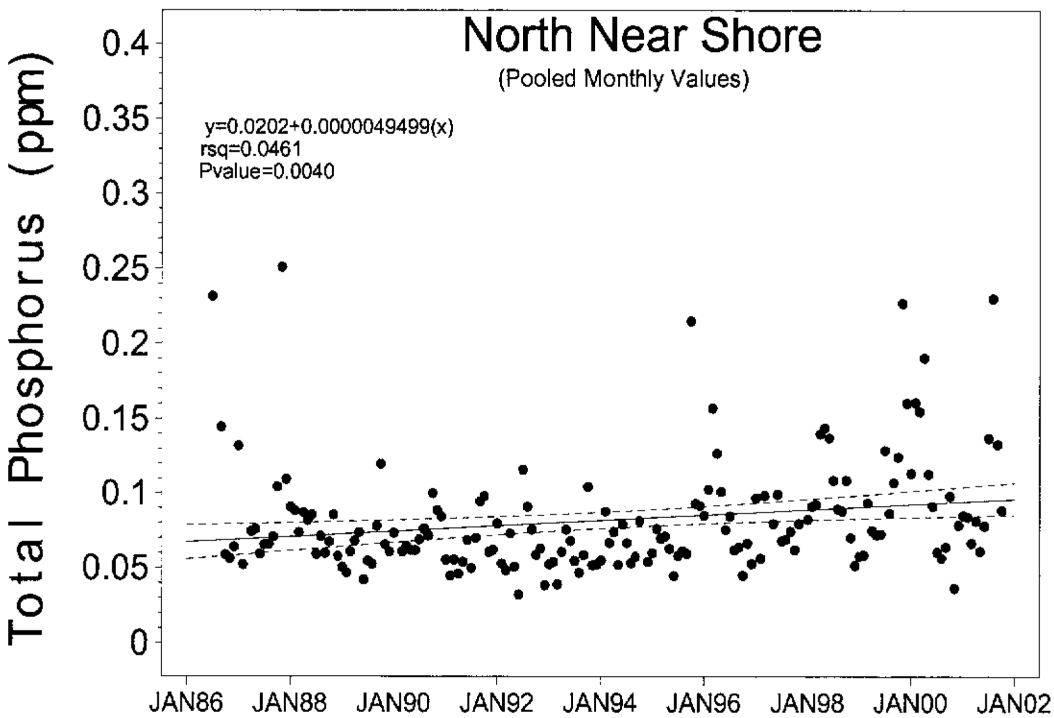


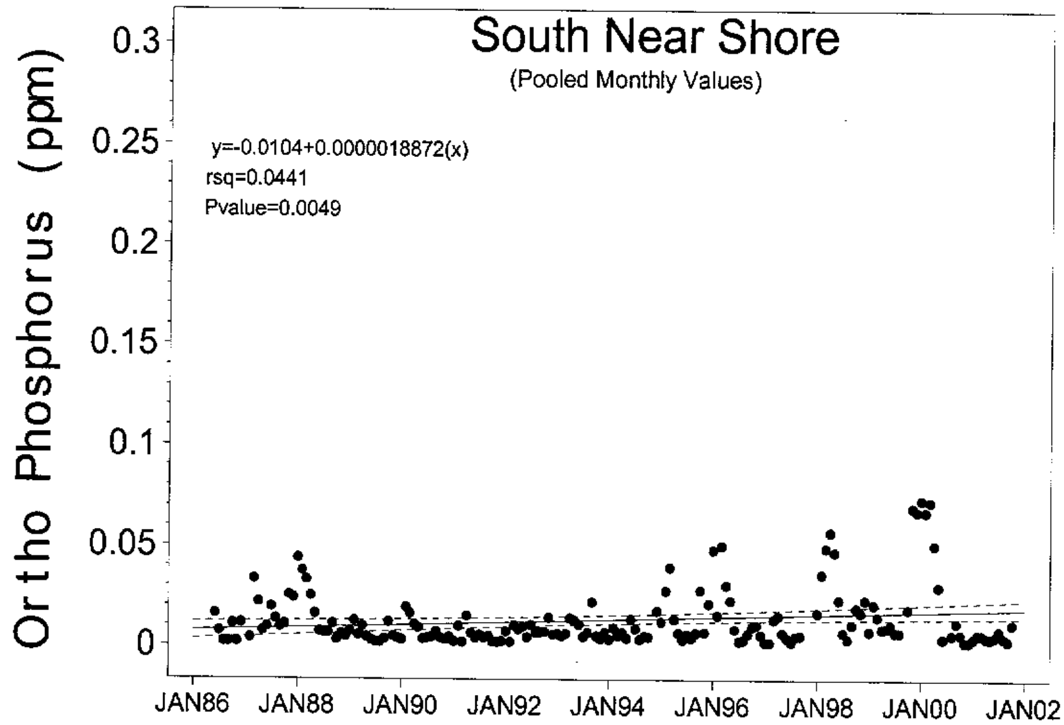
South Littoral
(Pooled Monthly Values)
y=-0.448+0.0000329151(x)
rsq=0.1559
Pvalue=0.0088
Ortho Phosphorus (ppm)
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN96
JAN97
JAN98
JAN99
JAN00
JAN01
JAN02

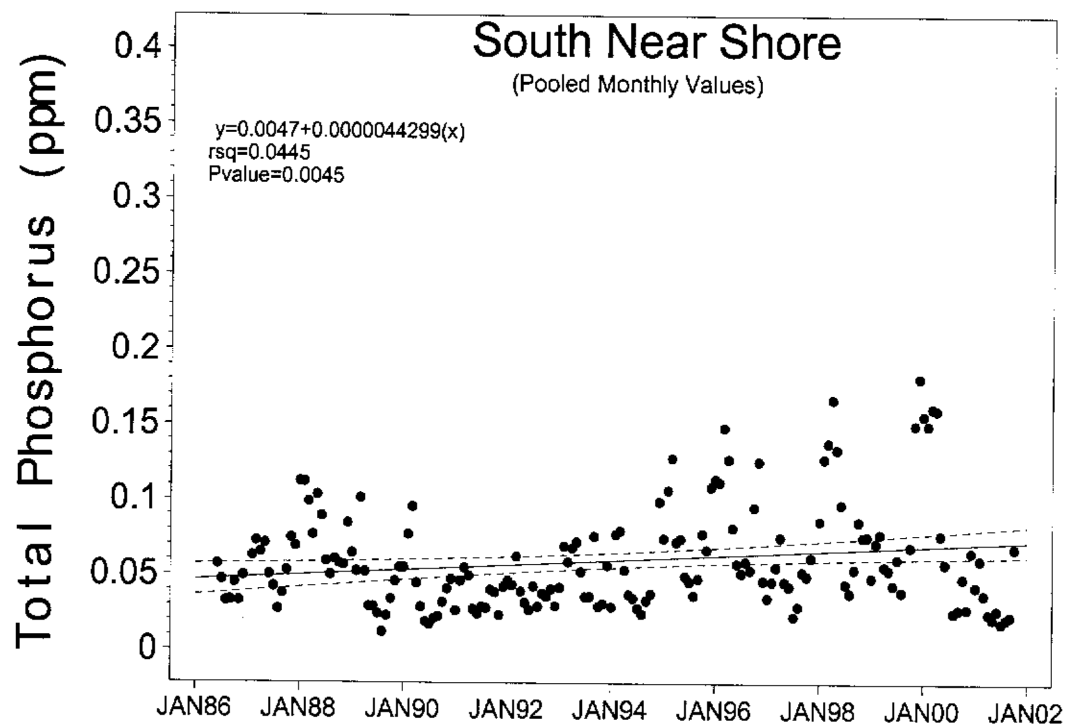


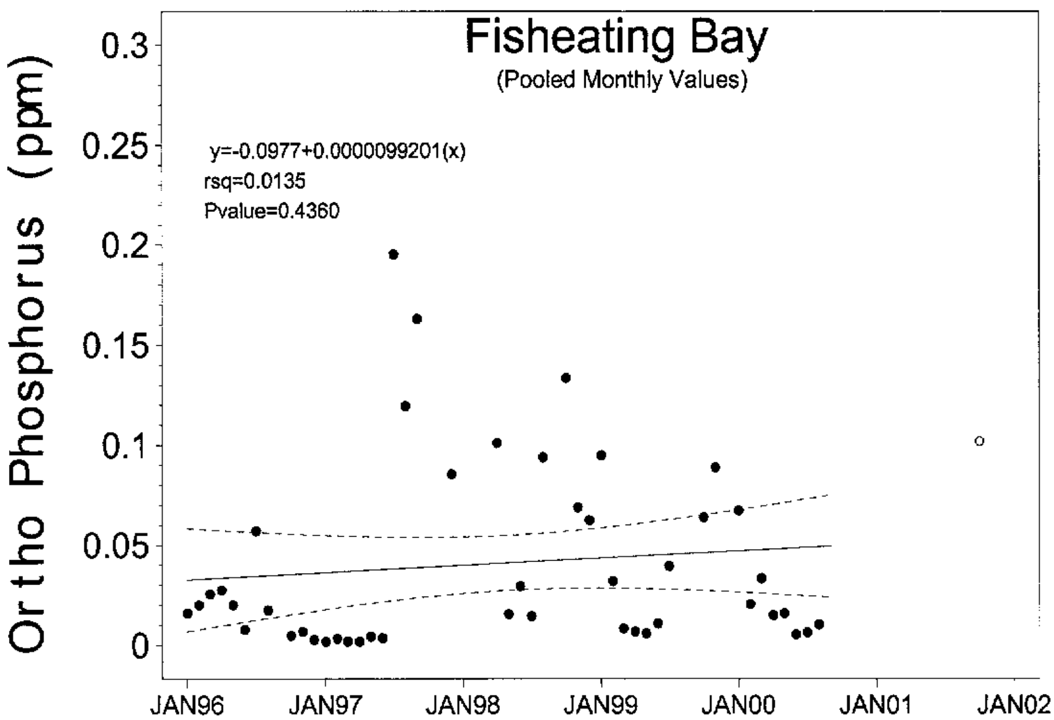
South Littoral
(Pooled Monthly Values)
y=-0.5132+0.0000385012(x)
rsq=0.1554
Pvalue=0.0098
Total Phosphorus (ppm)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN96
JAN97
JAN98
JAN99
JAN00
JAN01
JAN02


North Near Shore
(Pooled Monthly Values)
y=0.025+-0.0000002007(x)
rsq=0.0002
Pvalue=0.8680
Ortho Phosphorus (ppm)
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN86
JAN88
JAN90
JAN92
JAN94
JAN96
JAN98
JAN00
JAN02

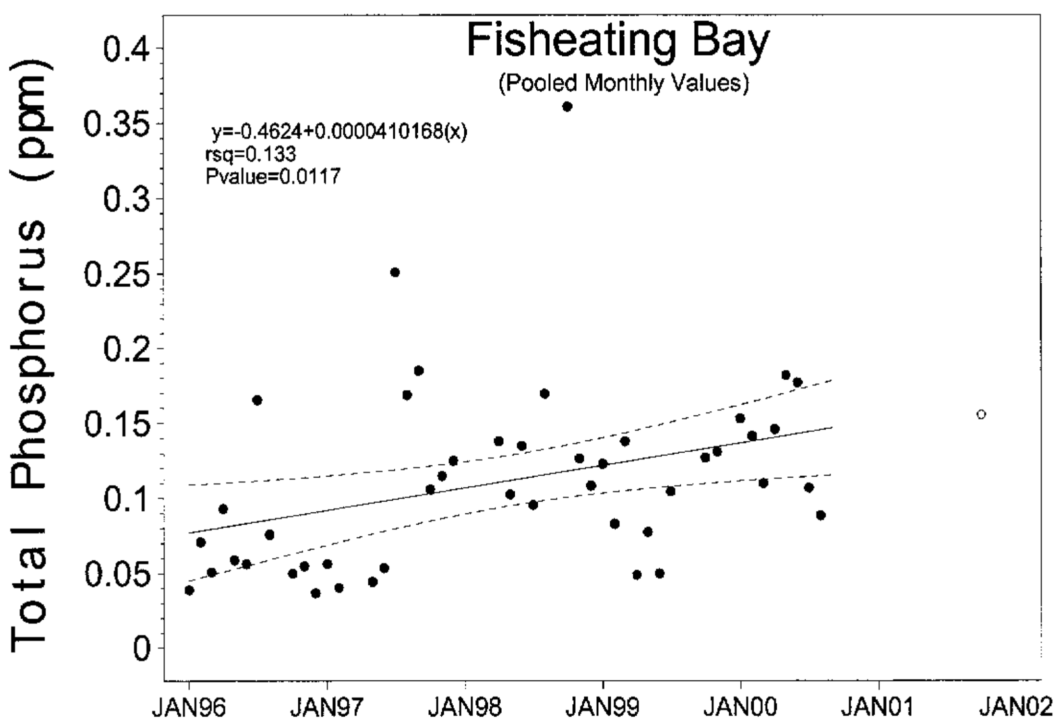

North Near Shore
(Pooled Monthly Values)
y=0.0202+0.0000049499(x)
rsq=0.0461
Pvalue=0.0040
Total Phosphorus (ppm)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN86
JAN88
JAN90
JAN92
JAN94
JAN96
JAN98
JAN00
JAN02


South Near Shore
(Pooled Monthly Values)
y=-0.0104+0.0000018872(x)
rsq=0.0441
Pvalue=0.0049
Ortho Phosphorus (ppm)
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN86
JAN88
JAN90
JAN92
JAN94
JAN96
JAN98
JAN00
JAN02


South Near Shore
(Pooled Monthly Values)
y=0.0047+0.0000044299(x)
rsq=0.0445
Pvalue=0.0045
Total Phosphorus (ppm)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN86
JAN88
JAN90
JAN92
JAN94
JAN96
JAN98
JAN00
JAN02

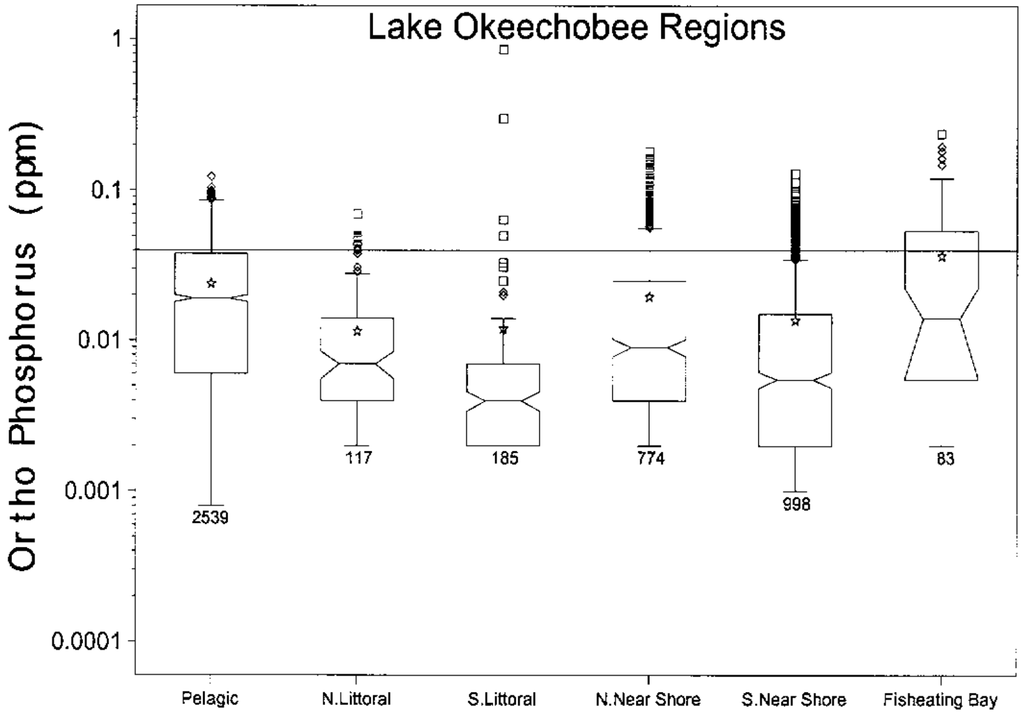


Fisheating Bay
(Pooled Monthly Values)
y=-0.0977+0.0000099201(x)
rsq=0.0135
Pvalue=0.4360
Ortho Phosphorus (ppm)
0
0.05
0.1
0.15
0.2
0.25
0.3
JAN96
JAN97
JAN98
JAN99
JAN00
JAN01
JAN02

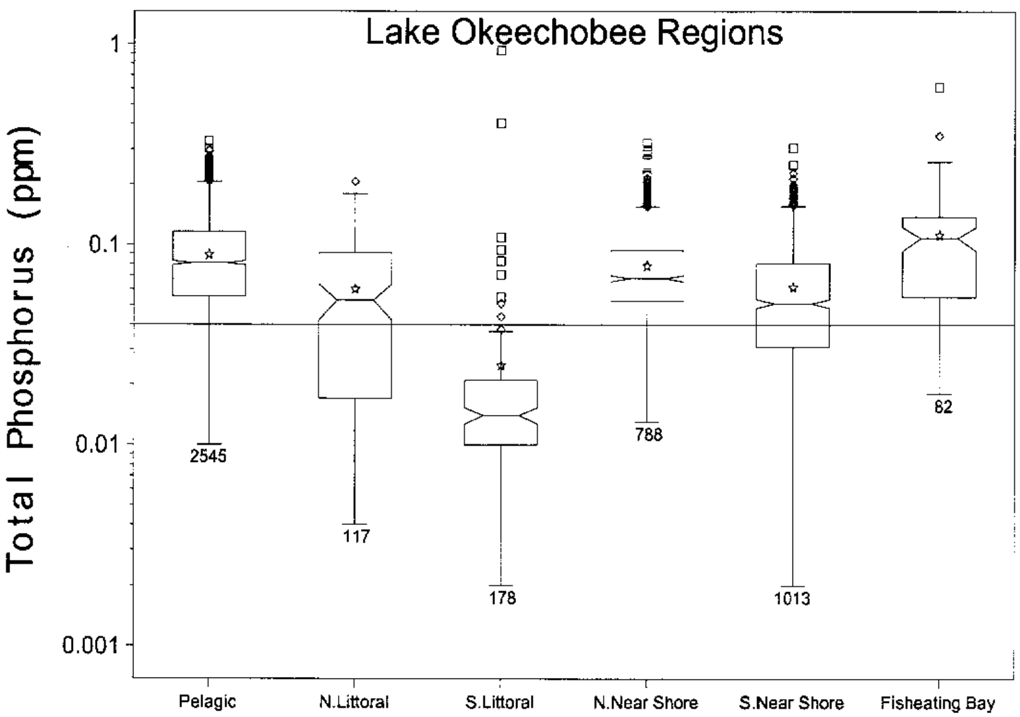


Fisheating Bay
(Pooled Monthly Values)
y=-0.4624+0.0000410168(x)
rsq=0.133
Pvalue=0.0117
Total Phosphorus (ppm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
JAN96
JAN97
JAN98
JAN99
JAN00
JAN01
JAN02

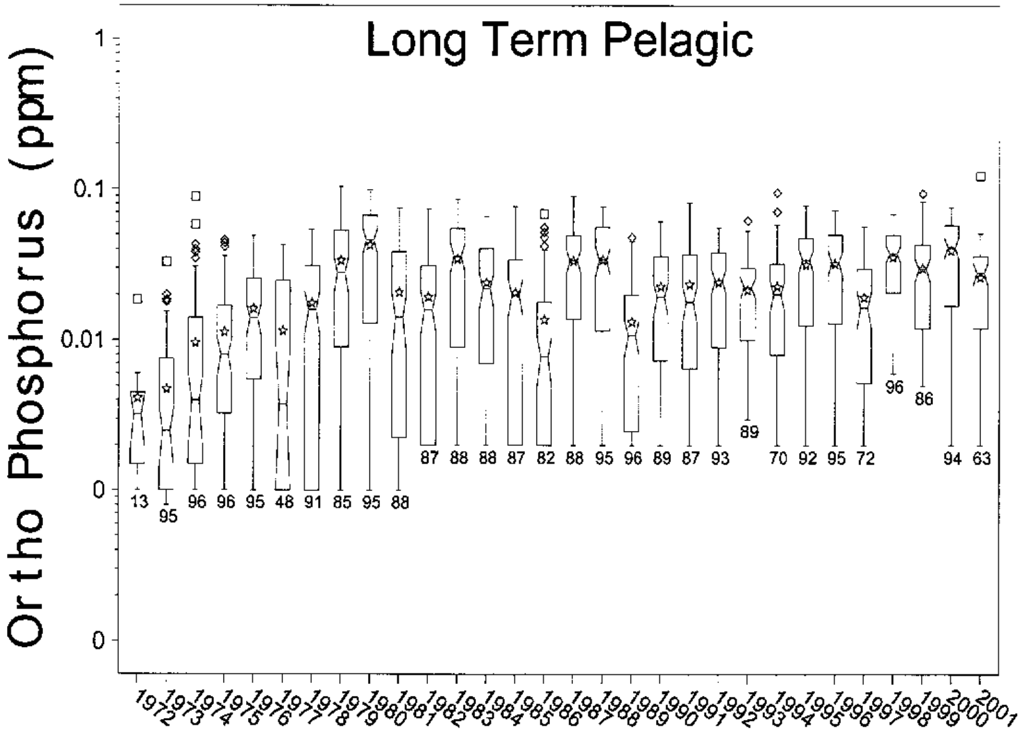
APPENDIX C

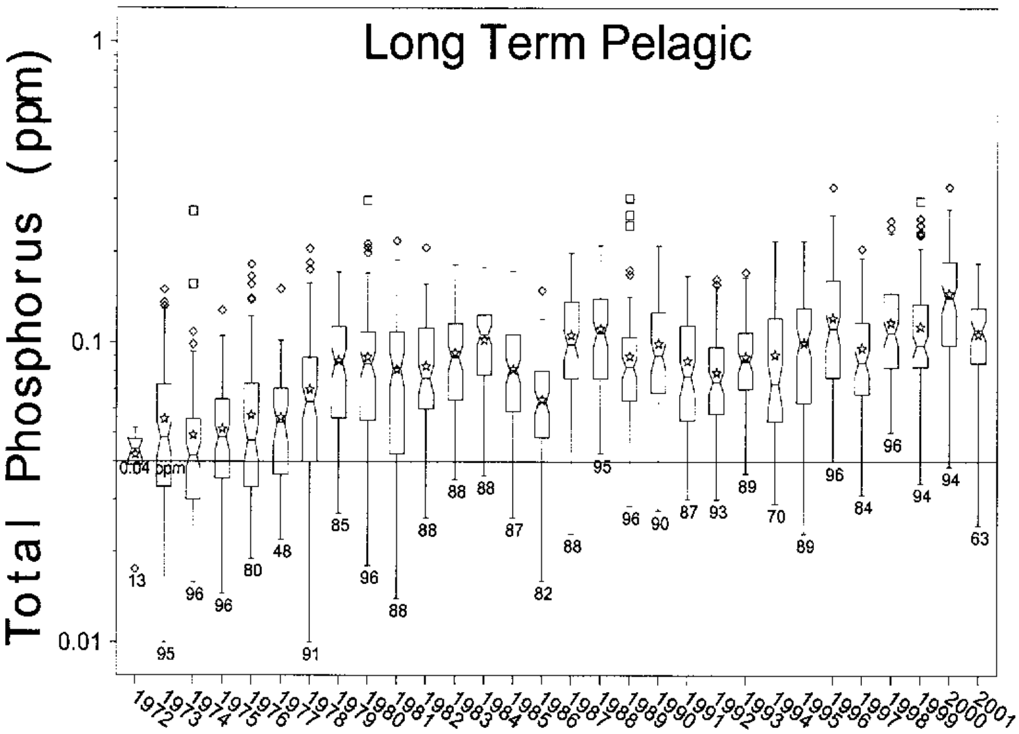


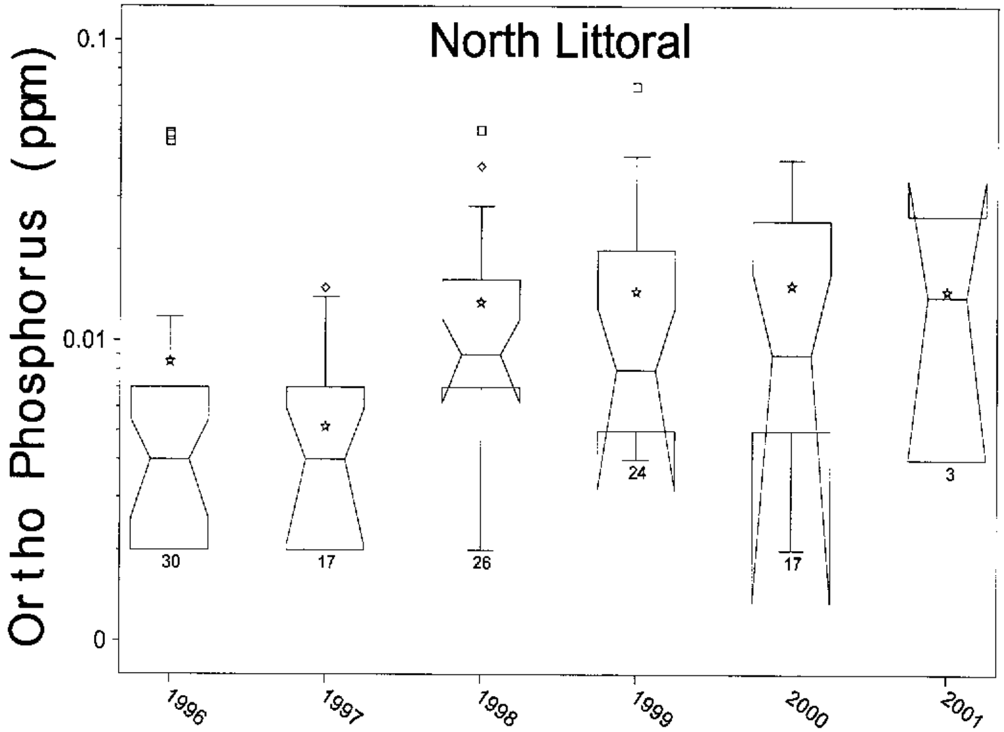
Lake Okeechobee Regions
Ortho Phosphorus (ppm)
1
0.1
0.01
0.001
0.0001
2539
117
185
774
998
83
Pelagic
N.Littoral
S.Littoral
N.Near Shore
S.Near Shore
Fisheating Bay

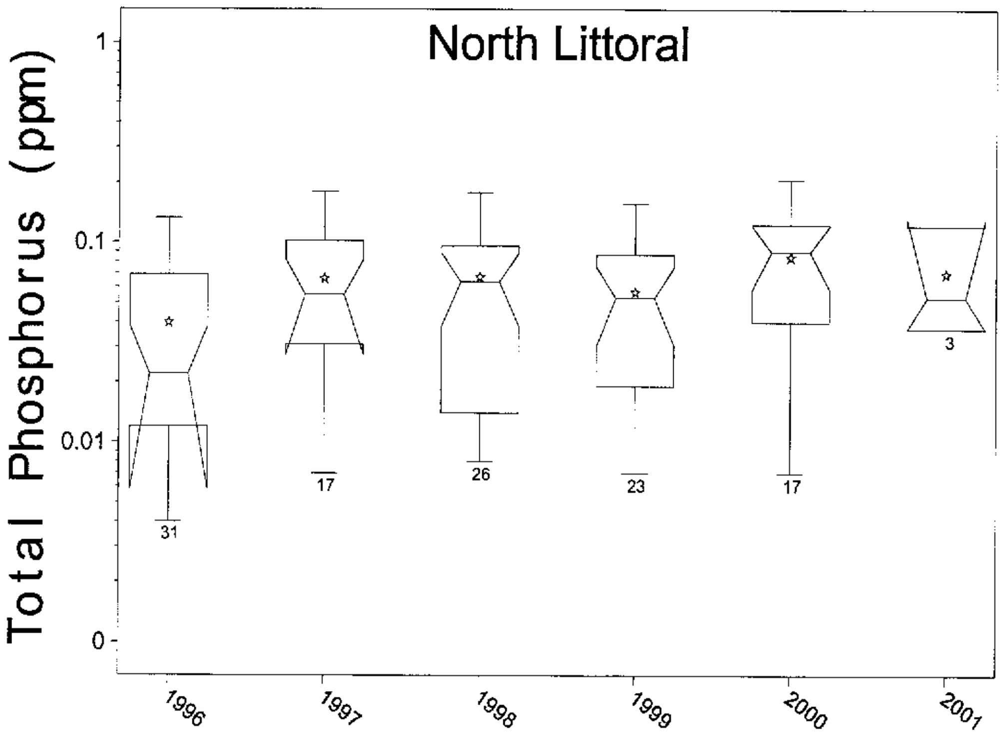


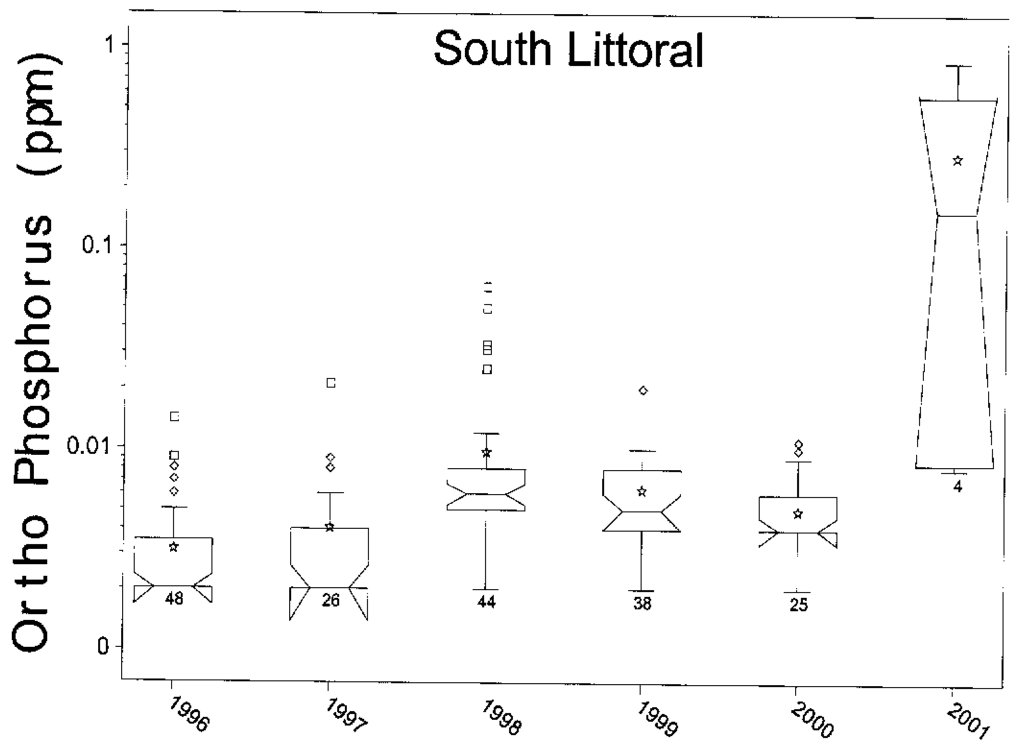
Lake Okeechobee Regions
Total Phosphorus (ppm)
1
0.1
0.01
0.001
2545
117
178
788
1013
82
Pelagic
N.Littoral
S.Littoral
N.Near Shore
S.Near Shore
Fisheating Bay

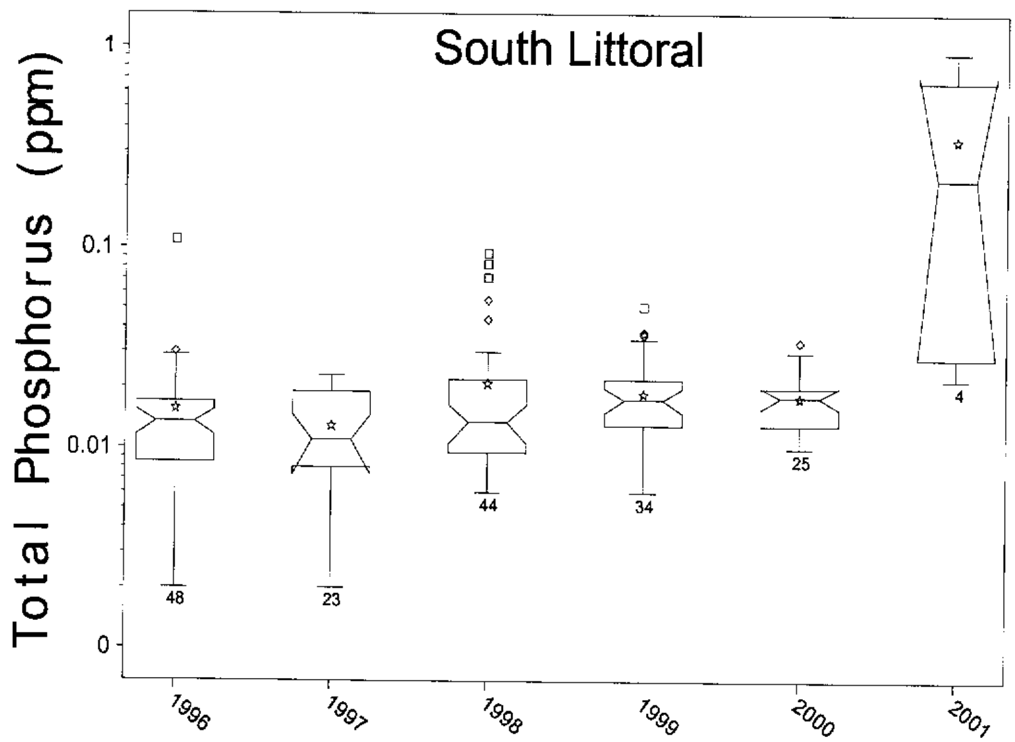

Long Term Pelagic
Ortho Phosphorus (ppm)
1
0.1
0.01
0
0
13 95 96 96 95 48 91 85 95 88
87 88 88 87 82 88 95 96 89 87 93 89 70 92 95 72 96 86 94 63
1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

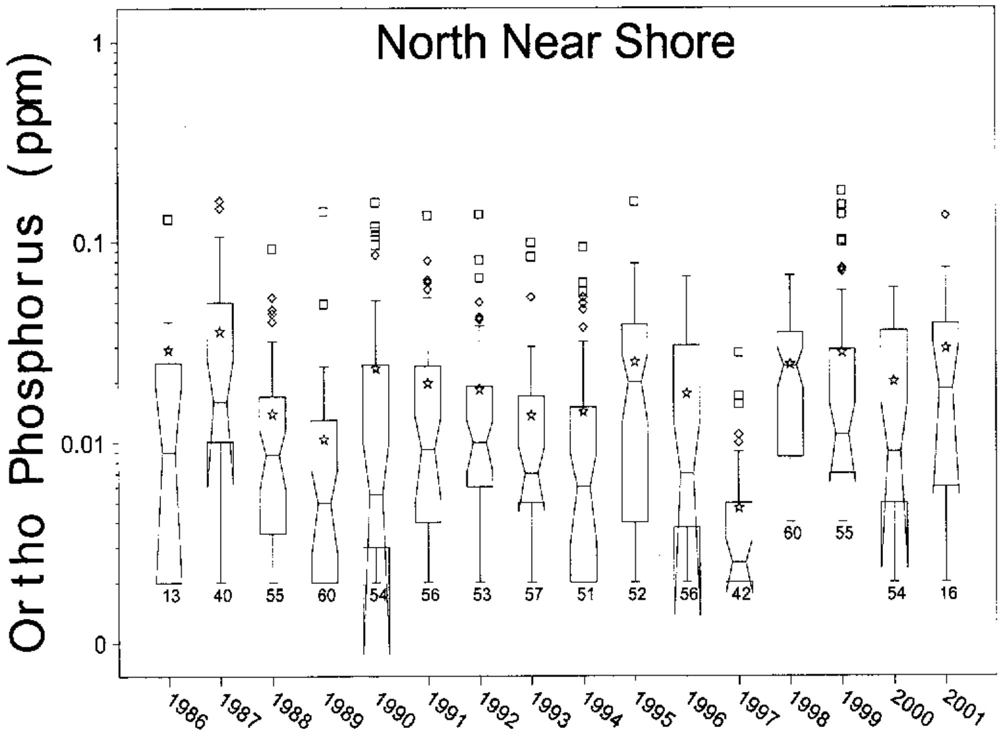

Long Term Pelagic
Total Phosphorus (ppm)
1
0.1
0.01
0.04 ppm
13 95 96 96 80 48 91 85 96 88 88 88 88 87 82 88 95 96 90 87 93 89 70 89 96 84 96 94 94 63
1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001


North Littoral
Ortho Phosphorus (ppm)
0.1
0.01
0
30
17
26
24
17
3
1996
1997
1998
1999
2000
2001


North Littoral
Total Phosphorus (ppm)
1
0.1
0.01
0
31
17
26
23
17
3
1996
1997
1998
1999
2000
2001


South Littoral
Ortho Phosphorus (ppm)
1
0.1
0.01
0
48
26
44
38
25
4
1996
1997
1998
1999
2000
2001


South Littoral
Total Phosphorus (ppm)
1
0.1
0.01
0
48
23
44
34
25
4
1996
1997
1998
1999
2000
2001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0.01
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52
56
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60
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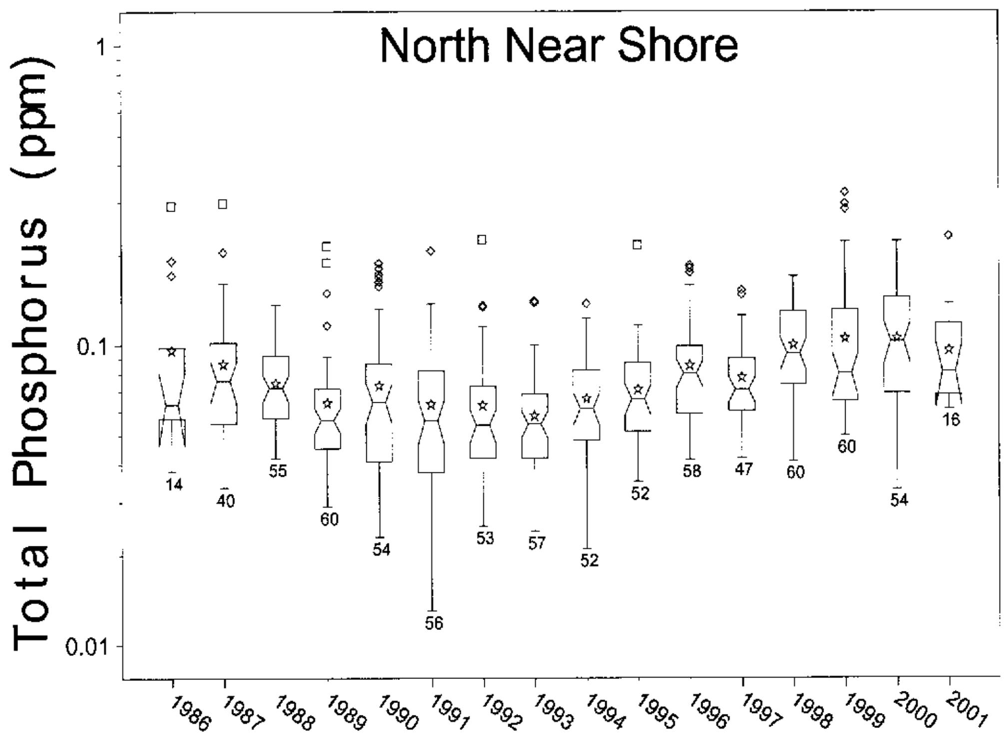
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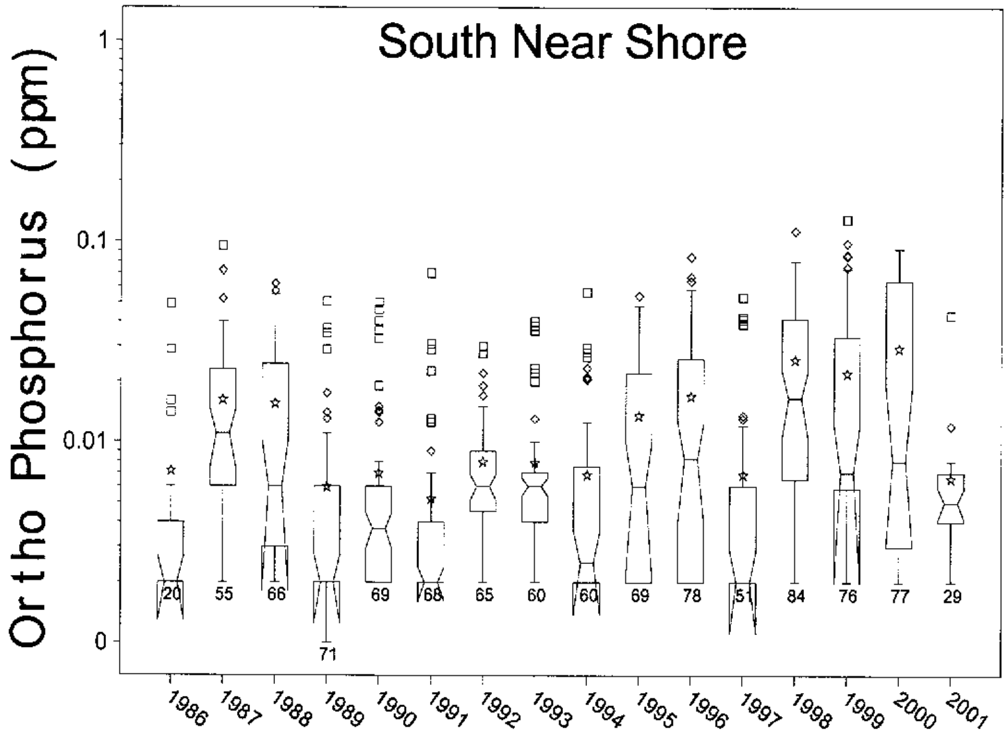
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Ortho Phosphorus (ppm)
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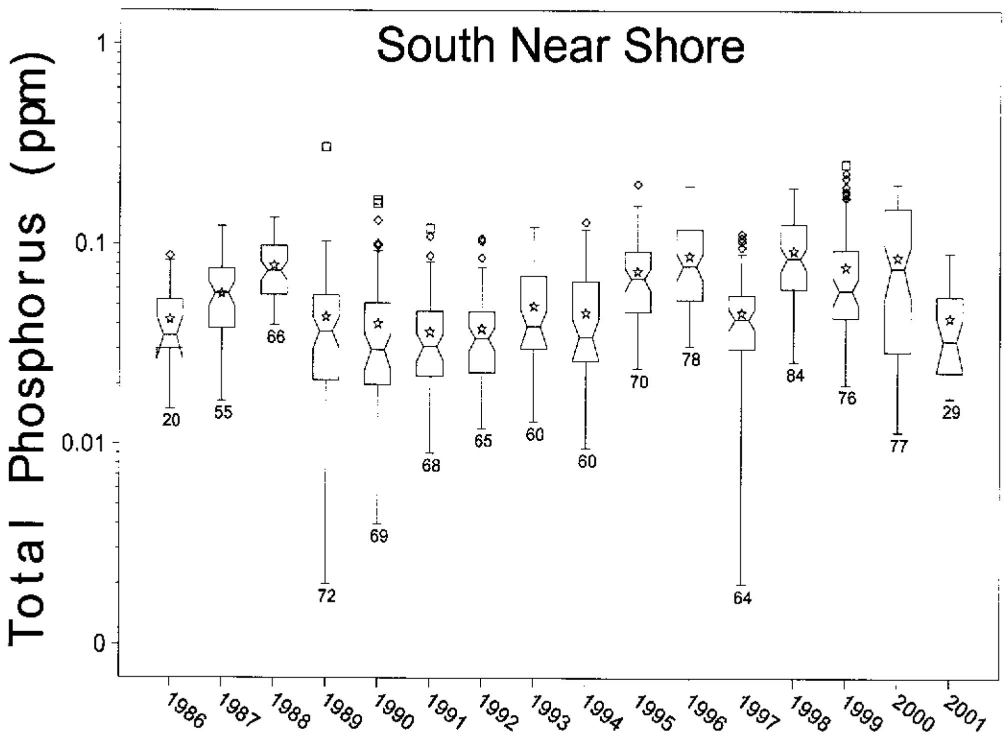
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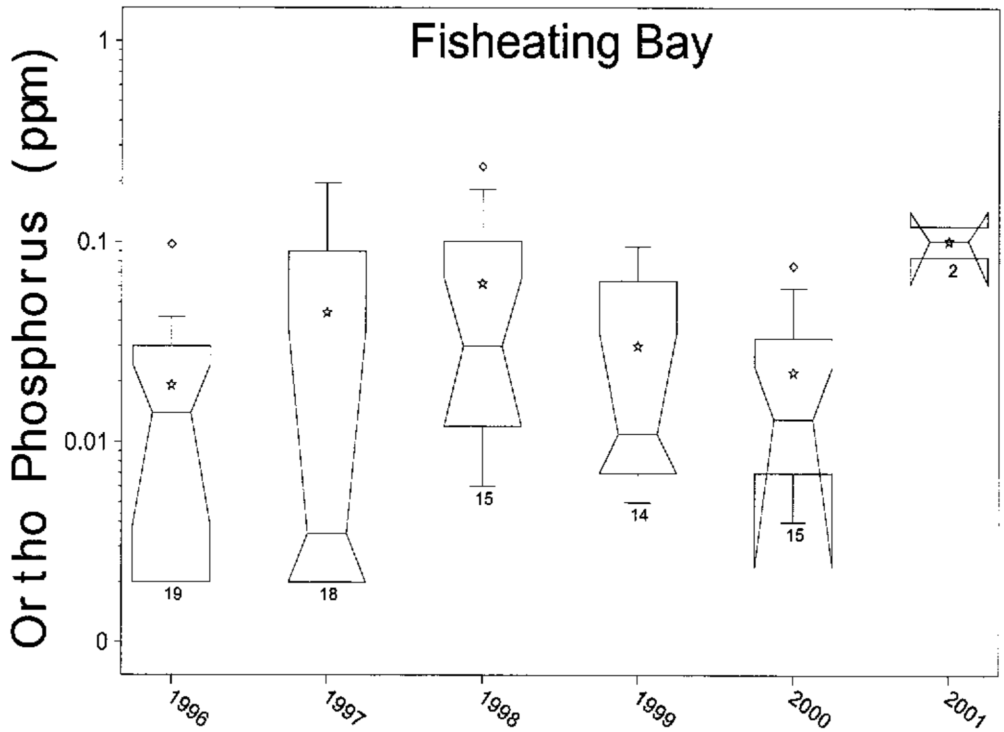
Fisheating Bay
Ortho Phosphorus (ppm)
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0.01
0
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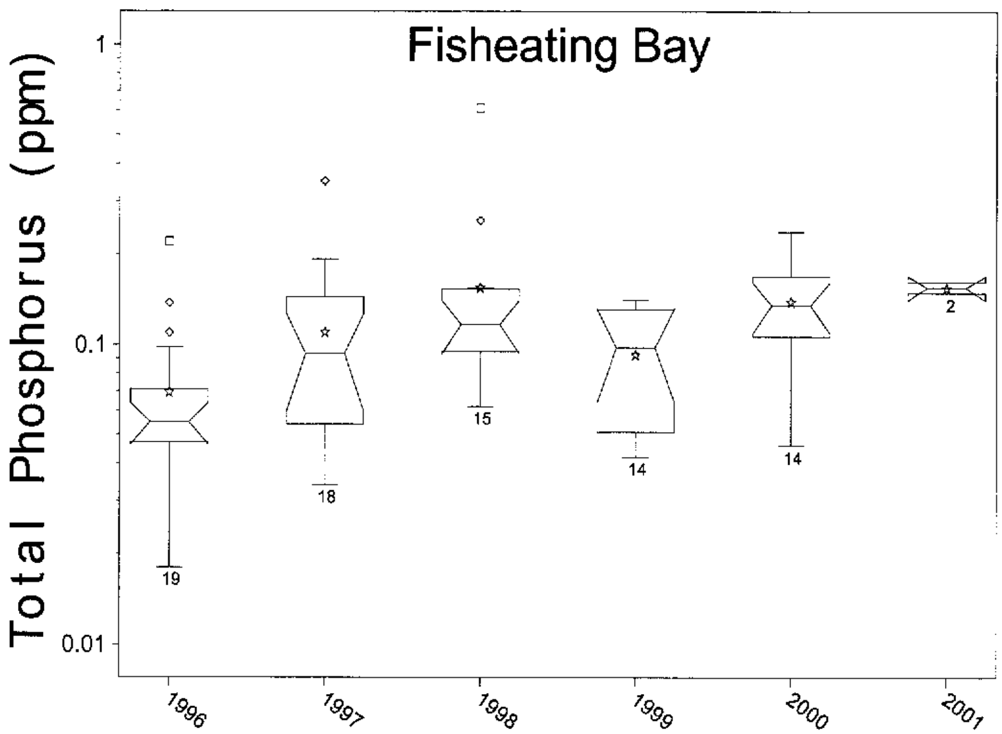
18
15
14
15
2
1996
1997
1998
1999
2000
2001


Fisheating Bay
Total Phosphorus (ppm)
1
0.1
0.01
19
18
15
14
14
2
1996
1997
1998
1999
2000
2001

APPENDIX 3

BASELINE CONDITIONS IN SELECTED TRIBUTARIES IN THE LAKE OKEECHOBEE WATERSHED

BASELINE CONDITIONS IN SELECTED TRIBUTARIES

IN LAKE OKEECHOBEE WATERSHED

Prepared by the

South Florida Water Management District

Alessandra Medri

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Steven Hill, M.S.

July 2003

BASELINE CONDITIONS IN SELECTED TRIBUTARIES IN LAKE OKEECHOBEE WATERSHED

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EXECUTIVE SUMMARY

The degradation of water quality in Lake Okeechobee has resulted from phosphorus loads that exceed levels considered acceptable to sustain a healthy ecosystem (Harvey and Havens, 1999). The need to improve water quality in the lake has led to the implementation of various phosphorus load reduction programs throughout the Lake Okeechobee Watershed (LOW) during the past three decades (Figure 1).

The purpose of this paper is to determine baseline conditions and summarize significant trends for total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and inorganic nitrogen (N) concentrations (NO_3 + NO_2-N + NH_4-N) collected from the District's ambient tributary monitoring network. The data analysis will focus on four priority basins in the watershed: S-191, S-154, S-65D, and S-65E (Figure1). Historically, these priority basins are the greatest source of external phosphorus loads to Lake Okeechobee (Harvey and Havens, 1999). These loads are a consequence of the major land uses in the basins and their associated Best Management Practices (BMPs).

This baseline analysis evaluated 24 of the 35 tributary stations, chosen for their strategic and physiographic location (Figure 2). Water quality data collected at these stations serve as a background in the assessment of phosphorus (P) contributions from dairies and other land uses in the watershed. Baseline data were compiled for each station in the priority basins during Water Years (WY), defined as the 12 month period starting on May 1 and ending on April 30, from 1992-2002. This baseline period is termed as the post-BMP implementation period. Most BMPs were implemented in these basins between Water Years (WY) 1989 and 1991. In addition, water quality data for WY1977 through WY1991 (Pre-BMP) were summarized and analyzed for comparative purposes. Trends in the water quality data were determined using regression analysis, notched box and whisker plots, time series graphs, and the seasonal Kendall's Tau test.

Results show that since the implementation of BMPs and other phosphorus-reduction programs, P loads and concentrations discharged from the Lake Okeechobee basins have declined (Anderson and Flaig, 1995). However, this decline has not been effective for the S-191, S-65D, and S-65E basins in the Post-BMP period. The greatest decrease in TP concentrations among the four priority basins was found at S-191 in the pre-BMP period. The declining trend has not continued during the Post-BMP period. The data indicate that TP concentrations may be increasing in this basin. Results show that only the S-154 basin exhibited a statistically significant reduction in TP concentrations during the post–BMP, period. SRP concentrations in the S-65D basin increased following implementation of the BMP programs.

During the baseline period, inorganic N concentrations increased in the priority basins (Figure 5). Based on the seasonal Kendall's -Tau analysis of data from the priority basins, only the S-154 and S65E basins exhibited statistically significant increasing trends of inorganic N concentrations (Table 4). Although the inorganic N trends in basins S-191 and S-65D were not statistically significant, the results suggest that, in the S-191 basin, inorganic N increased 0.01 mg L^{-1} (or 10 ppb) over a ten-year period.

Annual loads of TP from structures S-191, S-154, and S-65E were compared with median annual TP in the corresponding basins. Loads from the S-65D structure were not included in the comparison, because frequent ungauged discharges through an auxiliary structure (S-65DX) bypass the S-65D structure, therefore preventing the computation of a water budget for the basin. Based on the regression analysis, median TP concentrations in the S-191 basin exhibited a statistically significant trend with TP loads for both the pre-BMP and baseline period (Table 5). A strong and statistically significant correlation was also observed between annual median TP concentrations in the S-191 basin and annual flow-weighted mean TP concentrations at the outfall structure (S-191) to Lake Okeechobee (Figure 6). This indicates that TP concentrations within the S-191 basin watershed have a direct effect on discharge loads to the lake. In the remaining basins (S-154 and S-65E), median TP concentrations measured for stations within the basin were not significantly correlated to the annual flow-weighted mean TP concentrations calculated for the corresponding structures (Table 5).

During pre- and post-BMP periods, loads from structures S-154, S-191, and S-65E accounted for greater than 55 percent of the total load to the lake. Further, a ranking of the flow-weighted mean TP concentrations entering the lake shows that structures S-154 and S-191 consistently have the highest concentrations of any other inflow structure (Figures 7 and 8). Therefore, S-154 and S-191 contribute the most phosphorus to Lake Okeechobee.

Additional comparisons between pre- and post-BMP flow-weighted mean concentration or total load indicate that no change occurred at the S-154 structure. Significant reductions in both flow-weighted mean concentration and total load are observed at S-191. No changes are observed at S-65E, but total load increased, therefore increasing the discharge through the entire system.

The import of municipal residuals and poultry litter during the post-BMP period may have had an influence on the tributary water quality observed in the priority basins. Other activities, such as conversion of land use to higher intensity agricultural production, may have masked the effectiveness of the BMP programs. New program initiatives, including the Lake Okeechobee Protection Program and the Comprehensive Everglades Restoration Program (CERP), have targeted additional phosphorus control strategies in these four priority basins. A combination of BMPs and public works projects will be implemented to achieve further reductions in phosphorus loads from these basins. Information from this study can be used as the baseline to evaluate the effectiveness of these new initiatives.

INTRODUCTION

The degradation of water quality in Lake Okeechobee has resulted from phosphorus loads that exceed the value considered acceptable for sustaining a healthy ecosystem (Harvey and Havens, 1999). The need to improve water quality in the lake has led to the implementation of various phosphorus load reduction programs throughout the Lake Okeechobee Watershed (LOW) during the past three decades (Figure 1). The South Florida Water Management District (District) has maintained an extensive ambient water-quality monitoring network in these basins and sub-basins (located in the northern LOW) specifically to monitor tributary nutrient discharges to the lake.

The purpose of this paper is to determine baseline conditions and summarize significant trends for total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and inorganic nitrogen (N) concentrations (NO_3 + NO_2-N + NH_4-N) collected from the District's ambient tributary monitoring network. The data analysis will focus on four priority basins in the watershed: S-191, S-154, S-65D, and S-65E (Figure1).

Historically, these priority basins are the greatest source of external phosphorus loads to Lake Okeechobee (Harvey and Havens, 1999). These loads are a consequence of the major land uses in the basins and their associated Best Management Practices (BMPs). The efficiency of BMPs in reducing phosphorus concentrations in runoff may be reflected in water quality information collected at these locations. The water quality data may provide an indication of the effectiveness of past programs, and a baseline for evaluating programs that are currently being implemented for further reducing phosphorus loads to the lake.

While nitrogen (N) reduction goals have not been established for the lake, the environmental impact of nitrogen-containing compounds has been documented in several studies (Aldridge et al., 1995; Havens, 1995; Havens et al., 1996; Henry et al., 1985). Excessive N in freshwater bodies can cause eutrophication, or excessive growth of aquatic plants and algae, thus N is a parameter of concern in this report.

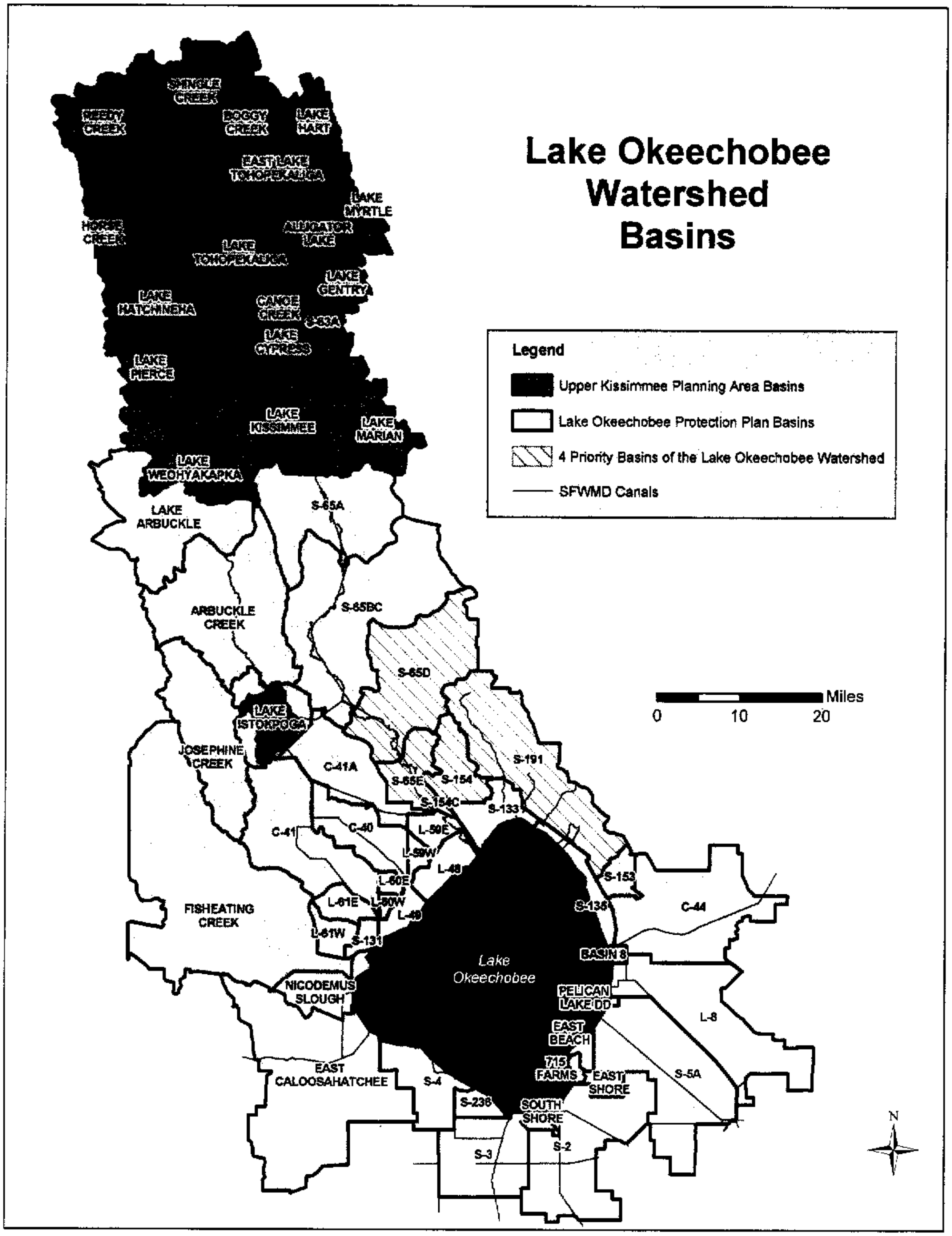


Figure 1. Lake Okeechobee watershed basins.

BACKGROUND

Lake Okeechobee is a large, shallow eutrophic lake located in south-central Florida, with a surface area of 1,730 km^2 (Figure 1). It is the largest freshwater lake in the southeastern United States. The lake is the central part of a large, interconnected aquatic ecosystem beginning with the upper chain of lakes and the Kissimmee River and ending with the Everglades and Florida Bay. It also is the major surface water reservoir of the Central and Southern Florida Flood Control Project. The lake continues to be one of the most important water resources in the state, and as such, provides a number of varying and sometimes conflicting uses to society and nature, including water supply for agriculture, urban areas, undeveloped areas, flood protection, and multi-million dollar sport and commercial fishing industries (Aumen, 1995). It also provides habitat for wading birds, migratory waterfowl, and the federally endangered Everglades Snail Kite (SFWMD, 2002). The excessive phosphorus loads currently impacting the Lake have been attributed to human activities in the watershed, in particular animal agriculture (Federico et. al.,1981; Flaig and Havens, 1995).

PHOSPHORUS REDUCTION PROGRAMS FROM 1980 THROUGH 2000

Phosphorus (P) loads to Lake Okeechobee have been studied since the 1970s. At that time, sources of P were identified, and programs were designed to reduce phosphorus discharges by controlling them at their source. One of the most significant sources initially identified was the S-191 basin, which contained the largest number of dairies and produced the greatest P loads of all the lake's tributary basins (Jones, 1987; Anderson & Flaig, 1995).

From 1982 to 1986, the District, the U.S. Department of Agriculture (USDA), and the U.S. Environmental Protection Agency (USEPA) sponsored the Rural Clean Waters Project (RCWP) to reduce phosphorus discharges from the S-191 basin by 50 percent (Stanley, 1992). This project targeted all agricultural lands within the basin, requiring implementation of basic BMPs. In 1987, the Florida Department of Environmental Protection (FDEP) implemented a Lake Okeechobee Dairy Rule requiring all dairies within the basin to construct and operate a system of BMPs for the purpose of reducing P discharges (FDEP, 1992). These BMPs were designed to collect, store, and land-apply dairy waste and runoff from high-intensity use areas. Although no numeric compliance limitations were specified in the Dairy Rule, a phosphorus discharge target of 180 parts per billion (ppb) was established in the 1989 Lake Okeechobee Surface Water Improvement and Management (SWIM) Plan (SFWMD, 1989), for all tributary inflows to the lake. Phosphorus control programs were expanded in 1989 when the District enacted the Works of the District Rule (Chapter 40E-61), requiring all nondairy land uses within the Lake Okeechobee basin to obtain a permit that would limit phosphorus discharge concentrations by implementing additional BMPs.

LAND USE IN THE PRIORITY BASINS

Land use in the northern part of the LOW is primarily agricultural and mostly improved pasture. This specific land use denotes cow-calf operations, where greater amounts of fertilizers are imported compared to dairy farms (Hiscock, 2002). Others principal land use types include dairy farms, tree (citrus and other fruit) crops, wetland, cropland, residential, rangeland, and upland forests (Table 1).

Table 1. Existing land use in the priority basins.

LAND USE IN THE PRIORITY BASINS[1]				
LAND USE TYPE	**S-65D (112,965 acres)**	**S-65 E (29,158 acres)**	**S-191 (120,354 acres)**	**S-154 (31,619 acres)**
Improved Pasture	51%	46%	53%	56%
Wetlands	23%	10%	10%	14%
Rangeland	6%	2%	2%	4%
Tree crops (citrus and other fruit)	5%	10%	3%	0%
Upland Forests	4%	8%	10%	3%
Cropland	3%	8%	1%	0%
Dairy farms	3%	9%	14%	13%
Other*	5%	7%	7%	10%
Total Percentage	**100%**	**100%**	**100%**	**100%**

[1] Compiled from the 1995 SFWMD Land Use modified by Mock-Ross and HDR Engineering, 2002.

* Other: residential, transp., comm., & utilities, open water, nurseries & vineyards, etc.

The recent P budget update for northern Lake Okeechobee watersheds indicates an increase of net P import for truck crops by 20 percent since 1991 (Hiscock, 2002). Truck crops are expanding in these basins, particularly in the S-65D basin, representing 32 percent of the net phosphorus import. Phosphorus sources not accounted for in the P budget report are the importation of Class B and Class AA residuals (sewage sludge) and poultry litter beginning in 1991 and continuing through 2000, both of which are high in inorganic N. The highest quality of residuals, known as Class AA, are distributed and sold as commercial fertilizers after being properly treated. Class B domestic wastewater residuals are more restrictive in their application because of a lower level of treatment.

Information from the FDEP indicates approximately a 20-fold increase in the spreading of residuals in Okeechobee and Highlands Counties from 1991 through 2000 (FDEP Memorandum, 1999). Much of the residual spreading in Okeechobee County occurred in the S-191 basin. During 1998 it was estimated that 354 dry tons of phosphorus from Class B residuals and 749 dry tons from Class AA residuals were applied in the Lake Okeechobee basin. It was also estimated that the Class B residuals were applied over approximately 5,000 acres of improved pasture grasses, such as bahia. Five ranches located in Lettuce Creek, a sub-basin of the S-191 basin, were receiving these Class B residuals.

Recent reports obtained from the Florida Department of Agriculture and Consumer Services (FDACS) and FDEP suggest that poultry litter is being spread at the rate of approximately 168 to 196 pounds of P per acre per year on 2,000 to 22,800 acres in the four priority basins. This equates to approximately 168 to 2300 short tons of P from poultry litter applied in the basin each year (FDEP Memorandum, 1999). Poultry litter is currently not regulated by either the state or federal government.

METHODS

Water Quality Monitoring Programs

The District operates and maintains an extensive water quality monitoring program for Lake Okeechobee and its basins. Monitoring of in-lake water and inflows at District-operated control structures has been on going since 1973. Monitoring expanded into the S-191 basin in 1977 because of concerns about phosphorus discharges. The network was later expanded to evaluate the impacts of the Rural Clean Waters Project (RCWP). Further expansion of the monitoring network occurred in 1987 by incorporating other basins to evaluate phosphorus reduction from the Dairy Rule and the Works of the District Rule. Currently, this monitoring network functions at three levels:

- **Basin monitoring** – control structures discharging to Lake Okeechobee;
- **Sub-basin and tributary** – monitor nutrient concentrations for trends in key locations within the northern Lake Okeechobee basins primarily responsible for large phosphorus loads;
- **Farm level monitoring** - monitor nutrients concentrations from edge of farm discharges for lands regulated by the Dairy Rule and the Works of the District Rule.

The basin monitoring program provides information to compute nutrient loads for discharges to the lake and to determine if such discharges are in compliance with Florida Class I water quality standards. The program is regulated by the FDEP through a permit (currently in the draft form). The tributary monitoring network provides nutrient concentration, chemical, and physical data for the evaluation of trends. Due to the high cost of collecting flow data, the computation of nutrient loads and flow-weighted analyses is not performed at this level of monitoring. Cost is also a factor at farm level monitoring. In fact, only nutrient concentrations are measured, simply to determine if the average discharges are meeting the target concentration.

Even though the LOW encompasses 29 basins (Figure 1), this baseline is focused on the four priority basins. As previously stated, these basins have been the greatest source of phosphorus loads to the lake. In terms of diversity of land use and number of sub-basins, S-191 is also the most complex (Albers, 2002).

Baseline Development-Data Analysis Period

The current tributary monitoring program within the priority basins encompasses 35 locations that provide representative information to characterize the quality of water and trends (Albers, 2002). This baseline analysis evaluated 24 of the 35 tributary stations because of their strategic and physiographic location (Figure 2). Water quality data collected at these stations serve as a background in the assessment of P contributions from dairies and other land uses in the watershed. Baseline data sets for water quality were compiled for each station in the priority basins during Water Years (defined as the 12 month period starting on May 1 and ending on April 30) 1992-2002. This baseline period is termed as the post-BMP implementation period. Most BMPs were implemented in these basins between Water Years (WY) 1989 and 1991. In addition, water quality data for WY1977 through WY1991 (Pre-BMP) were summarized and analyzed for comparative purposes. Seasonal variability was also evaluated. The data were analyzed further for Wet (June-November) and Dry (December-May) season for the baseline period.

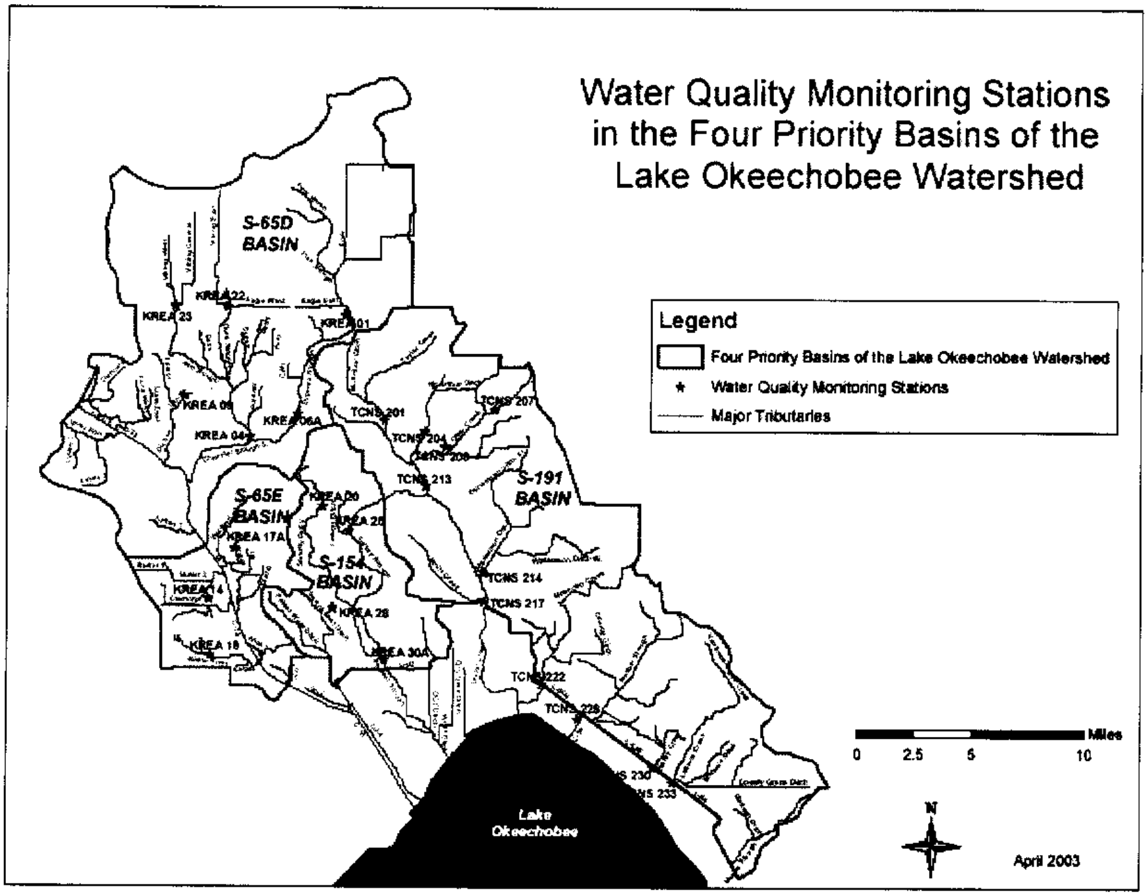


Figure 2. Tributary monitoring network in the priority basins.

Water Quality Monitoring

All water quality data used for this report were retrieved from the District's database (DBHydro). This database serves as a repository for all water quality and hydrologic data collected by the District in South Florida (Germain, 1998). Biweekly and monthly water quality samples were collected in the priority basins by automatic samplers, grab sampling, or a combination of both methods. Water chemistry samples analyzed include TP mg P L^{-1}, SRP mg P L^{-1}, total kjeldahl nitrogen (TKN, mg N L^{-1}), ammonium nitrogen (NH_4-N, mg N L^{-1}), nitrate + nitrite-nitrogen (NO_3 + NO_2-N, mg N L^{-1}). Data collection methods and nutrient budget calculations are described further in James et al. (1995a).

For the purpose of this analysis, concentrations less than the method detection limit (MDL) were converted to a value of ½ MDL (Table 2). Total nitrogen (TN, mg N L^{-1}) was calculated from measurements of NO_3 + NO_2-N, NH_4-N, and TKN. Methods of Quality Assurance and Quality Control utilized in the compilation of the resulting data were consistent with those used in the 2000 Everglades Consolidated Report (SFWMD, 2000).

Table 2. SFWMD Lab Analyte Reporting Level.

Parameter	Reporting Level (MDL)	Units
NH4	0.009	mg L^{-1}
NO2	0.004	mg L^{-1}
OPO4	0.004	mg L^{-1}
TPO4	0.002	mg L^{-1}
TKN	0.050	mg L^{-1}
NO_3 + NO_2-N	0.004	mg L^{-1}

Descriptive Statistical Analysis

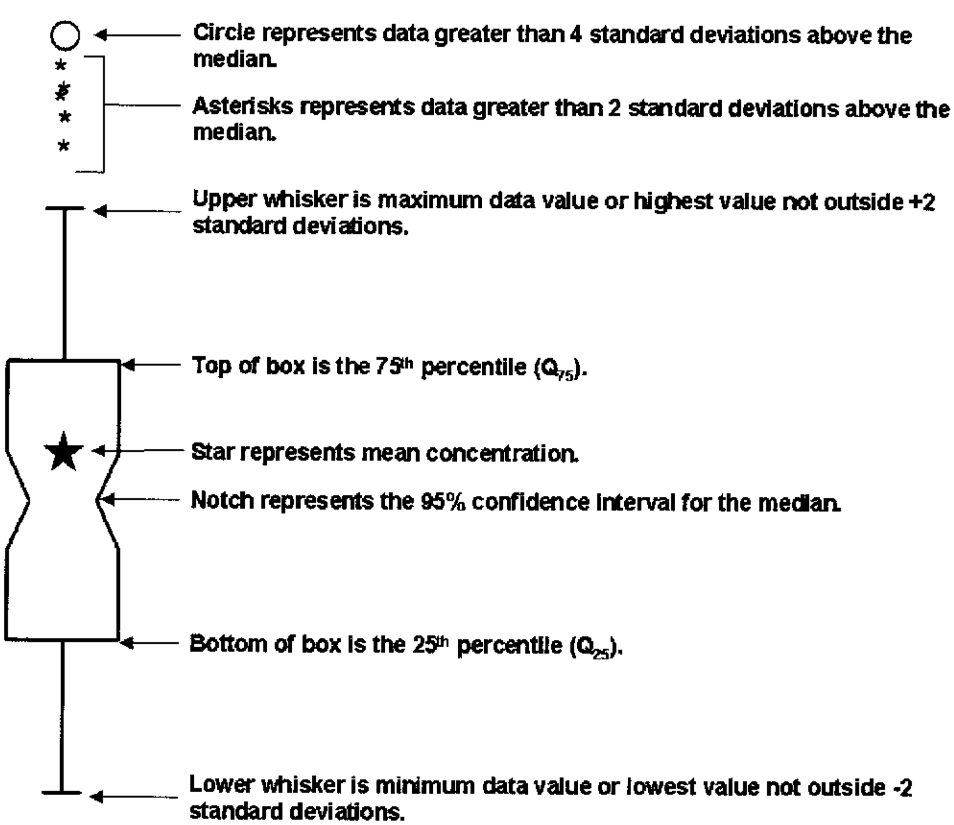
Summary statistics reported here include number of samples, means, medians, minima, maxima, and standard deviations for each of the basins (Appendix A). For statistical purposes, monthly median concentrations were used in determining trends for each of the 24 stations and basins. The median is a robust estimate of the center of a sample of data, since outliers have little affect on it. Trends in the water quality data were determined using regression analysis, notched box-and-whisker plots, time series graphs, and the seasonal Kendall's -Tau test.

The seasonal Kendall's -Tau analysis is a non-parametric test frequently used to detect trends for water quality time series. It is a rank-order statistic that can be applied to time series exhibiting seasonal cycles, missing and censored data, and indications of non-normality (Yu and Zou, 1993). It allows serial correlation and the presence of detection-limited values. For the purpose of this report evaluation, a value of $p \leq 0.05$ is considered significant. Results of the seasonal Kendall's -Tau test can indicate if a statistically significant increase or decrease in P and N is present between the stations and basins.

Description of Notched Box-And-Whisker Plots

Notched box-and-whisker plots displayed in this report summarize selected statistical properties of the data sets (Figure 3). These plots have been used to test for statistical significance between data sets at roughly a 95-percent confidence interval, to detect changes in constituent concentration variability over time, and to determine if trends exist. Notched box-and-whisker plots consist of the median, the lower quartile, the upper quartile, the smallest and the largest values in the distribution of a given set of data. The central box represents the values from the lower to upper quartiles (25th to 75th percentile). The middle line represents the median of the data, and the notch in the box is the 95-percent confidence interval of the median. When notches between boxes do not overlap, the medians are considered significantly different. The notched box-and-whisker plot used for these summaries follows McGill et al., 1978.

Figure 3. Description of Notched Box-And-Whisker Plots in this report.



1. Notches surrounding the medians provide a measure of the significance of differences between notched box plots. If the notches about two medians do not

overlap, the medians are significantly different at about a 95-percent confidence level.

2. At times, the variability in a data set may be quite high. When highly variable data are presented in a notched box-and-whisker plot, the width of the notch may be greater than the 25th or 75th percentile. When this occurs, the box plot appears as if it is folded from the end of the notch back toward the median. This is done automatically by the statistic program to save space within the figure being presented.

RESULTS

Water Quality Evaluation and Analysis

Median pre-BMP water quality concentrations were generally higher than baseline levels (Table 3). Although most parameter concentrations decreased during these two periods, inorganic N and TP increased in the S-65D Basin (Table 3).

Table 3. Comparison of pre-BMP and post-BMP (baseline) median concentrations.

Parameter	S-154		S-191		S-65D		S-65E	
(mg L^{-1})	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Inorganic Nitrogen	0.074	0.056	0.492	0.184	0.035	0.053	0.095	0.042
Total Nitrogen	2.15	1.99	2.20	1.61	1.38	1.32	2.12	1.51
Soluble Reactive Phosphorus	1.497	0.971	0.588	0.274	0.070	0.040	0.428	0.372
Total Phosphorus	1.7265	1.069	0.763	0.383	0.121	0.132	0.767	0.327

Of the four priority basins, S-191 exhibited the greatest decrease in parameter concentrations from pre-BMP to post-BMP (Figure B-1 in Appendix B). Constituent concentrations within this basin decreased approximately two-fold.

This decrease may be attributed to the implementation of several BMPs during the mid-1980s on cow/calf and dairy operations in the basin. In fact, median phosphorus concentrations decreased from 2.0 mg L^{-1} in WY1978 to 0.52 mg L^{-1} in WY1988. Other constituents of interest (inorganic N, SRP, and TN) also exhibited similar declines (Figures B-2, B-3, and B-4 in Appendix B).

Nutrient concentrations in basins S-154, S-65E, and S-65D did not decline as much as observed for S-191 (Table 3). These observations may be attributed to a lesser degree of BMP implementation in these basins, because the focus and funding of the RCWP was mostly on S-191.

Regression analyses of annual median TP concentrations in all the basins during the baseline period (WY1992 to WY2002) show an apparent increase in median TP concentrations for the S-191 and S-65D basin (Figure 4). However, the seasonal Kendall's -Tau test indicates that these increased TP concentrations are not statistically significant (Table 4). Only SRP in the S-65D basin exhibited a statistically significant increase.

Total P concentrations for the S-154 and S-65E basins exhibit a decreasing trend during the baseline period (Figure 4). The observed decrease in median TP concentrations during the baseline period was statistically significant only at S-154. Additionally, SRP concentrations also decreased significantly for this basin (Table 4). Both TP and SRP decreased in the S-154 basin by approximately 0.5 mg L^{-1}. Although median phosphorus concentrations have generally declined since 1991, episodic increases have been observed in the S-154 basin from WY1995 to WY1997, and from WY2000 to WY2002 (Figure 4). Of the three stations analyzed in this basin, only one (KREA 28) exhibited a statistically significant decrease during the entire period of record. This particular station represents the cumulative impact of the Dairy Rule and BMPs implemented on six large agricultural operations, including three large dairies and one cow/calf operation.

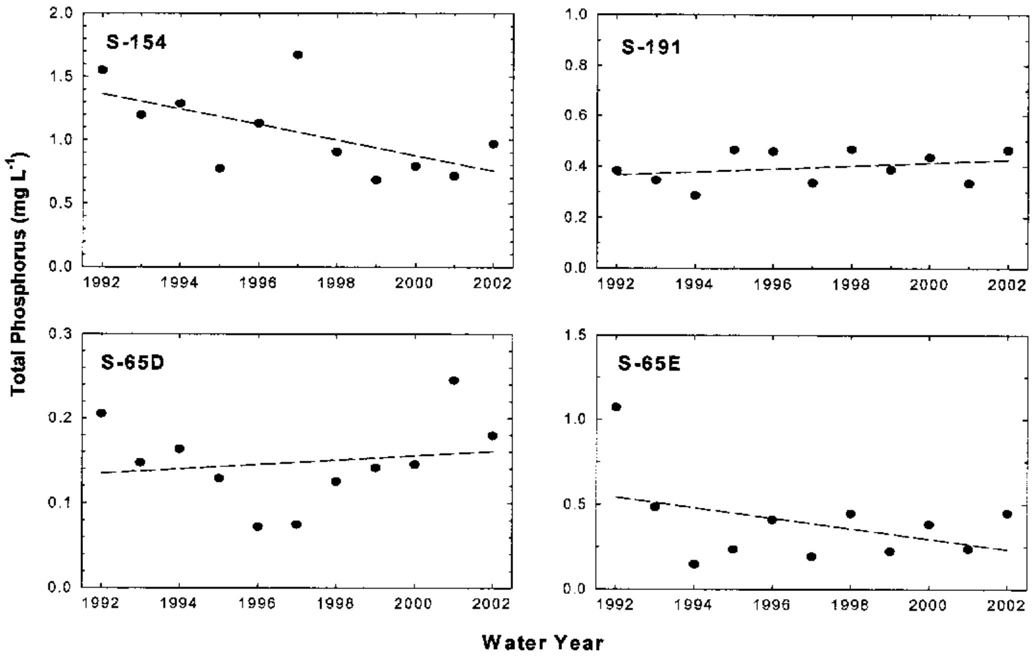


Figure 4. Regression of annual median total phosphorus concentrations over the baseline period in the four priority basins.

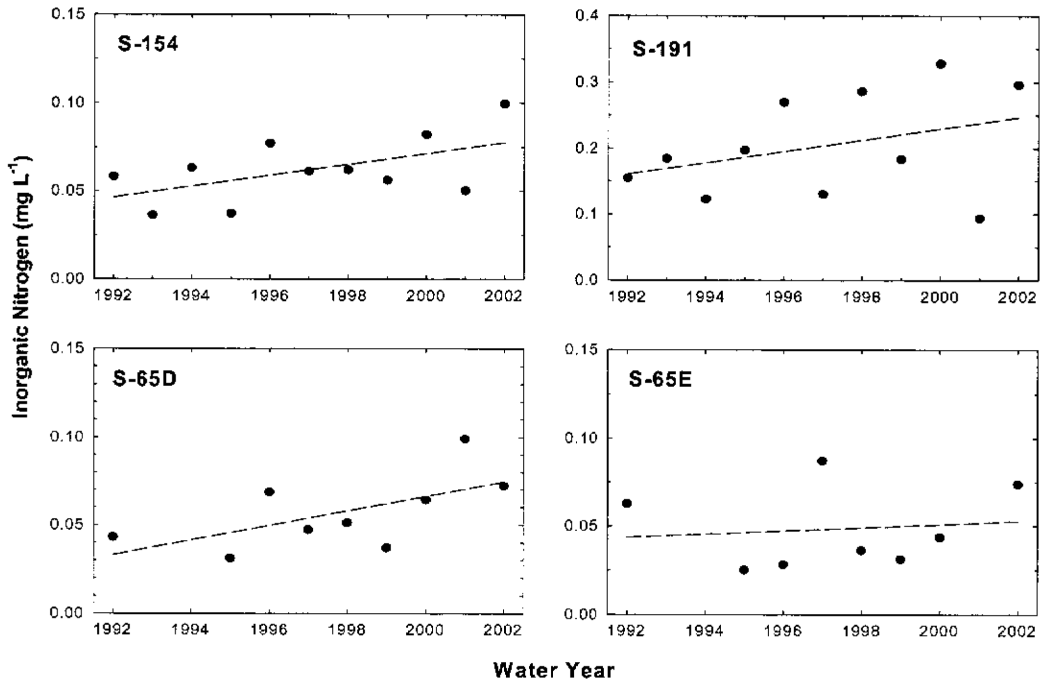


Figure 5. Regression of annual median inorganic nitrogen concentrations over the baseline period in the four priority basins.

Table 4. Summary of Seasonal Kendall's-Tau results based on monthly median concentrations for the four priority basins during the post-BMP period (WY1992 – WY 2002).

Basin	Parmeter	Slope	P-Value[1]	No. of Months Samples Collected	No. of Months No Samples Collected
S154	Inorganic Nitrogen	0.004	***<0.001***	100	44
	Soluble Reactive Phosphorus	-0.052	***0.04***	100	44
	Total Nitrogen	0.012	0.50	98	46
	Total Phosphorus	-0.056	***0.04***	100	44
S191	Inorganic Nitrogen	0.010	0.08	138	6
	Soluble Reactive Phosphorus	0.004	0.50	139	5
	Total Nitrogen	0.022	0.18	138	6
	Total Phosphorus	0.003	0.52	139	5
S65D	Inorganic Nitrogen	0.004	0.07	97	47
	Soluble Reactive Phosphorus	0.005	***0.001***	98	46
	Total Nitrogen	0.042	0.08	98	46
	Total Phosphorus	0.003	0.29	132	12
S65E	Inorganic Nitrogen	0.005	***0.002***	68	76
	Soluble Reactive Phosphorus	0.009	0.35	68	76
	Total Nitrogen	0.048	***0.03***	68	76
	Total Phosphorus	-0.007	0.34	129	15

[1] The P values have been adjusted for significant serially correlated data.
Bolded and italicized data indicate statistically significant slopes.

During the baseline period, inorganic N concentrations increased in the priority basins (Figure 5). Based on the seasonal Kendall's -Tau analysis of the data from the priority basins, only the S-154 and S65E basins exhibited statistically significant increasing trends of inorganic N levels (Table 4). Although the increasing inorganic N concentrations in basins S-191 and S-65D were not statistically significant, the results suggest that in the S-191 basin, inorganic N levels increased 0.01 mg L^{-1} (or 10 ppb) over a ten-year period.

Box-and-whisker plots for the baseline period for the four priority basins (Appendix C) support the findings of these statistical analysis. Wet season plots showed little variation, while dry season plots exhibit greater variability and significant data gaps due to dry conditions. No significant declining trends were observed for all the parameters in the four priority basins, with the exception of a slight decrease in TP and SRP in the S-154 basin. A general increasing trend in all the parameters was observed from WY 2001 to WY2002 for all the priority basins.

Seasonal Kendall's -Tau Analysis of the Stations

The seasonal Kendall's-Tau test was also used to determine trends for the baseline period for each station in the four priority basins. This analysis revealed which stations within a basin show statistically significant increases or decreases. The information is relevant in identifying problematic areas, possible sources of the nutrients (which is beyond the scope of this paper), and parameters of concern.

Results show a statistically significant increase in inorganic N, TP, and SRP concentrations at station TCNS 233 in the S-191 basin (Table D-1 in Appendix D). This particular water quality station is located downstream of a poultry litter spreading site. Other stations within this basin exhibiting a significant, increasing trend in both P and inorganic N concentrations are TCNS 230 for TP and TCNS 209 and TCNS 213 for inorganic N (Table D-1 in Appendix D).

Statistically significant increases in inorganic N, TN, and P median concentrations have been observed at KREA 01 station in the S-65D basin (Table D-2 in Appendix D). This particular water quality station is located downstream of the largest truck crop operation in the basin. Stations KREA 23, KREA 09, and KREA 04 also exhibited statistically significant increases in P median concentrations.

In the S-65E basin, only one station (KREA 17A) exhibited statistically significant increases in all parameters (Table D-3 in Appendix D). Here, also, residuals and poultry litter spreading have been reported (FDEP Memorandum, 1999). The dominant land use of S-65E in terms of phosphorus imports is truck crops (Hiscock, 2002).

Seasonal Kendall's - Tau indicates statistically significant decreases in P and SRP in the S-154 basin (Table D-4 in Appendix D). The dominant land use in terms of phosphorus imports in the S-154 is dairy farming. However, as mentioned earlier, only KREA 28 exhibited a statistically significant decrease during the entire period of record. In the S-154 basin there were no reports of residuals or poultry litter spreading, and there are no truck crop operations in the current basin land use.

Phosphorus Loads to Lake Okeechobee and Basin Phosphorus Concentrations

Annual loads of TP from structures S-191, S-154, and S-65E were compared with median annual TP in the corresponding basins. Loads from the S-65D structure were not included in the comparison, because frequent ungauged discharges through an auxiliary structure (S-65DX) bypass the S-65D structure, therefore preventing the computation of a water budget for the basin. Based on the regression analysis, median TP concentrations in the S-191 basin exhibited a statistically significant trend with TP loads for both the pre-BMP and baseline period (Table 5). A strong and statistically significant correlation was also observed between annual median TP concentrations in the S-191 basin and annual flow-weighted mean TP concentrations at the outfall structure (S-191) to Lake Okeechobee (Figure 6). This indicates that TP concentrations in the S-191 basin watershed have a direct effect on loads to the lake.

In the remaining basins (S-154 and S-65E), median TP concentrations measured for stations within the basin were not significantly correlated to the annual flow-weighted mean TP concentrations calculated for the corresponding structures (Table 5). This is expected. Runoff from the S-65E basin represents a relatively small percentage of the discharge conveyed through the S-65E structure. Although a similar correlation (to that observed for S-191) between basin median TP and structure flow-weighted mean concentrations is expected for the S-154 basin, a comparison between the S-191 and S-154 basins may explain the difference. The S-191 basin drainage system is characterized by an extensive canal system that conveys water very efficiently to the outlet. The S-154 basin drainage system is characterized primarily by large wetlands and slough systems, which may provide some attenuation and treatment.

Table 5. Summary of regression analysis between median total phosphorus concentrations in the basin (X) and total phosphorus loads at the discharge structures to Lake Okeechobee (Y). (Bold and Italicized values indicate statistical significance.)

Period	Basin	Regression Equation	No. of Samples	R^2	P-Value
Pre-BMP Period (WY1978-Wy1991)	S-154	$Y = -7.61X + 15.9 \times 10^4$	5	0.20	0.45
	S-191	$\boldsymbol{Y = 8.27X - 3.04 \times 10^4}$	***14***	***0.36***	***0.023***
	S-65E	$Y = 192X - 0.36 \times 10^4$	6	0.51	0.11
BMP Period (WY1992 - WY2002)	S-154	$Y = 2.05X + 4.54 \times 10^4$	11	0.084	0.38
	S-191	$\boldsymbol{Y = 530X - 13.1 X 10^4}$	***11***	***0.46***	***0.022***
	S-65E	$Y = 154X + 8.39 X 10^4$	11	0.10	0.34

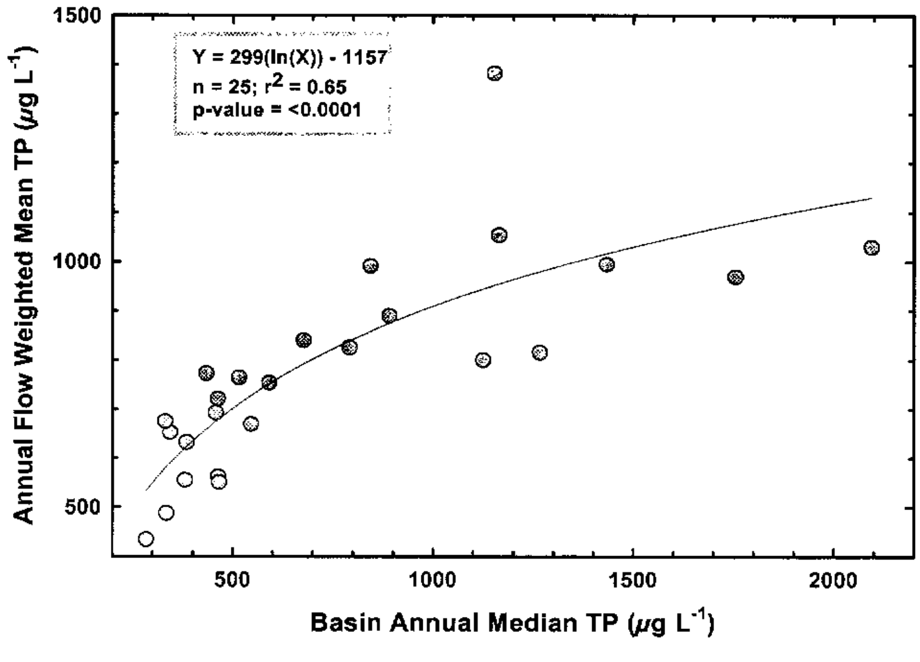


Figure 6. Regression of annual median TP concentration in the S-191 basin and the annual flow-weighted mean TP concentration at structure S-191 over the period of record.

Annual TP loads and the corresponding flow-weighted mean average TP concentration for each structure that discharges into Lake Okeechobee was determined for the pre- and post-BMP periods (Figures 7 and 8). Both the loads and flow-weighted mean concentrations are ranked from the highest to lowest input to the lake. During both periods, loads from structures S-154, S-191, and S-65E accounted for greater than 55 percent of the total load to the lake. Further, a ranking of the flow-weighted mean TP concentrations entering the lake shows that structures S-154 and S-191 consistently have the highest concentrations of any other inflow structure (Figures 7 and 8). This observation indicates that of all the basins draining into the lake, S-154 and S-191 contribute the most phosphorus to Lake Okeechobee.

Additional comparisons between pre-BMP and post-BMP flow-weighted mean concentration or total load indicate that no change occurred at the S-154 structure. A significant reduction in both (flow-weighted mean concentration and total load) is observed at S-191. No changes are observed at S-65E, but total load increased, therefore increasing the discharge through the entire system.

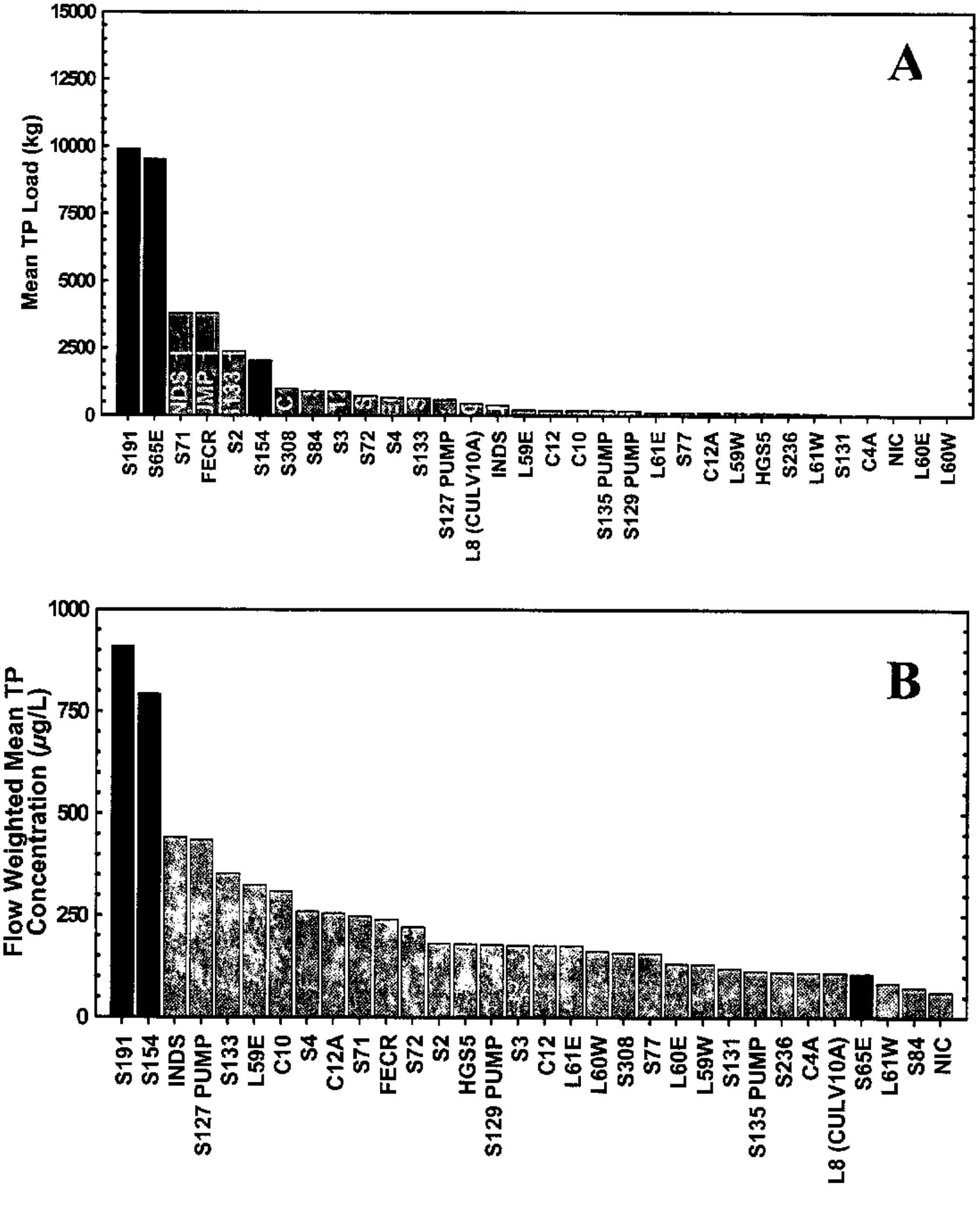


Figure 7. Ranking of inflow stations with the highest total phosphorus load (A) and flow-weighted mean total phosphorus concentration (B) for the pre-BMP period (WY1974 through WY1991). The darker bars represent priority basins S-154, S-191, and S-65E.

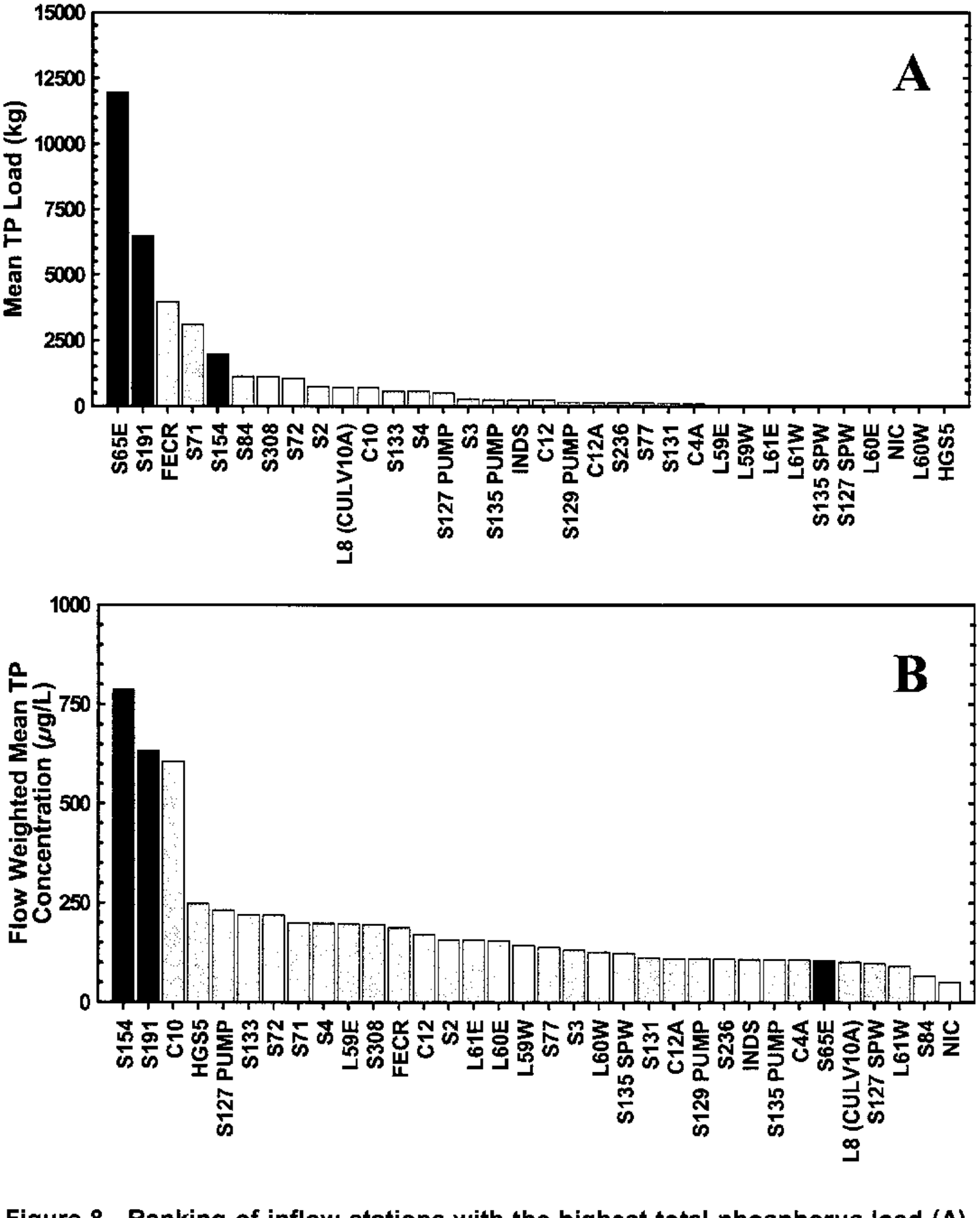


Figure 8. Ranking of inflow stations with the highest total phosphorus load (A) and flow-weighted mean total phosphorus concentration (B) for the post-BMP period (WY1992 through WY2002). The darker bars represent priority basins S-154, S-191, and S-65E.

Future Phosphorus Reduction Programs

The 1999 Florida Watershed Restoration Act -Total Maximum Daily Load (TMDL) Bill- (SB 2282) (Chapter 403.067, F.S.) and the 2000 Lake Okeechobee Protection Plan (LOPP) (Section 373.4595, F.S.) are two comprehensive statutory programs aimed at reducing phosphorus loads to Lake Okeechobee. In May 2001, the Florida Department of Environmental Protection (FDEP) adopted a phosphorus TMDL for Lake Okeechobee in the amount of 140 metric tons (of which 35 metric tons is assumed to be from atmospheric deposition) based on a 5-year rolling average to achieve an in-lake phosphorus concentration target of 40 $\mu g\ L^{-1}$. The current 5-year average P loading to the lake is approximately 600 tons (SWIM, 2002).

The LOPP committed the State of Florida to restore and protect Lake Okeechobee by reducing the inputs of P to the lake from the watershed. This reduction in P levels can be accomplished by achieving and maintaining compliance with water quality standards in Lake Okeechobee and its tributary waters to meet the lake's TMDL for P (LOPP, 2001). The program sets forth a series of activities and deliverables for these coordinating agencies: the District, FDEP, and FDACS.

The Comprehensive Everglades Restoration Plan (CERP), authorized by Congress in the 2000 Water Resources Development Act (WRDA), will also target reductions in phosphorus loads to Lake Okeechobee through the Lake Okeechobee Watershed Project (LOWP). The LOWP incorporates 4 of the 68 projects aimed to implement the objectives of CERP. The four LOWP components are (1) North of the Lake Storage, (2) Taylor Creek/Nubbin Slough Reservoir Assisted Stormwater Treatment Area (RASTA), (3) Lake Okeechobee Water Quality Treatment Facilities, and (4) Tributary Sediment Dredging (Restudy Integrated Feasibility Study and Programmatic Final EIS, April 1999). Each of these LOWP components requires P water quality targets, which will determine the phosphorus load reduction that will be expected from each component. It is not expected that the LOWP components will provide all the P reduction (approximately 460 metric tons) necessary to achieve the TMDL (Shugar, 2002). However, this project, combined with the other initiatives by the state and the District, will maximize the efforts in intercepting P loads in the watershed before they reach the lake.

An integral part of the LOWP is the monitoring of water quality, flow, and other physical parameters (e.g., temperature, pH, dissolved oxygen). The U.S. Geological Survey (USGS) and the U. S. Army Corps of Engineers (USACE) entered into a cooperative agreement for the design and operation of a basin-scale monitoring system that will complement and supplement the existing District's monitoring program. All of these monitoring programs will provide information necessary to document the effectiveness of these projects in reducing phosphorus loads and other parameters of concern to Lake Okeechobee. USGS monitoring stations are shown in Figure 9.

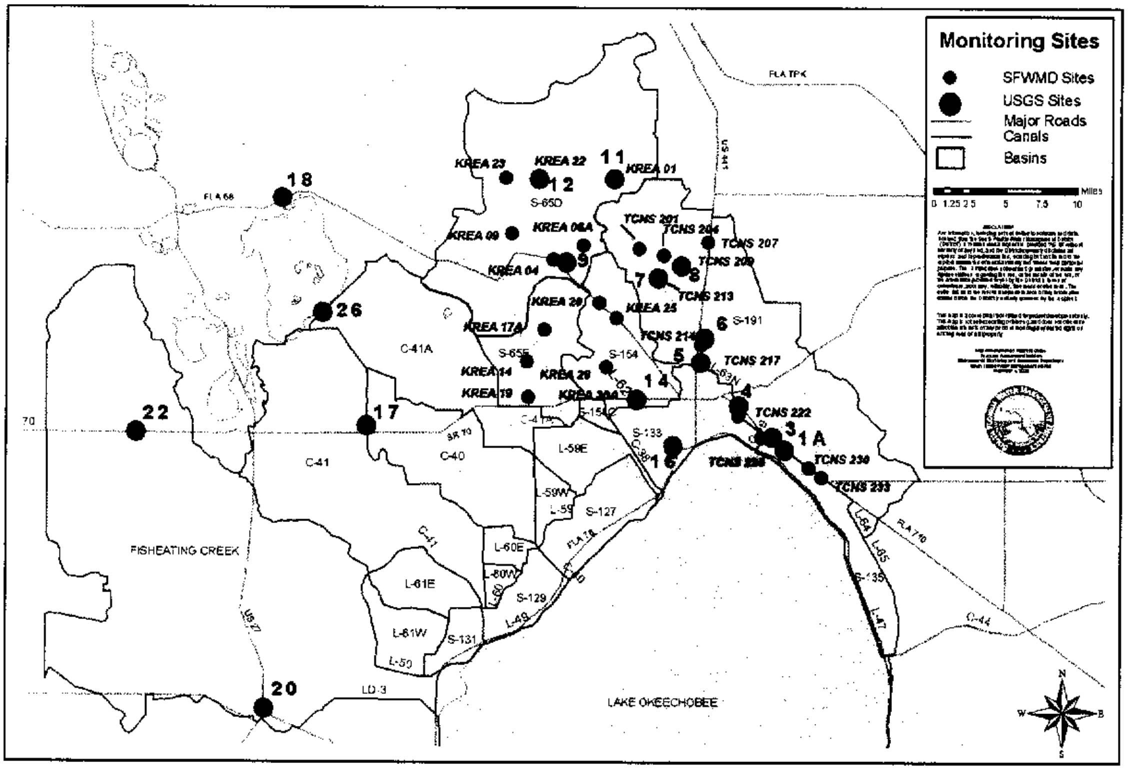


Figure 9. LOWP area with selected District water quality monitoring stations and USGS stations.

Since the implementation of BMPs and other P-reduction programs, P loads and concentrations discharged from the Lake Okeechobee basins have declined (Anderson and Flaig, 1995). However, this decline has not been effective for the S-191, S-65D, and S-65E basins from 1991 to present. The greatest decrease in TP concentrations among the four priority basins was found at the S-191 basin in the pre-BMP period versus the post-BMP period. The declining trend has not continued during the baseline period. The data indicate that TP concentrations may be increasing in this basin. The S-154 basin was the only basin where significant TP reductions were found in the post BMPs period.

The documented results of this study are relevant to the future objectives of the LOPP and CERP. It confirms the need for a watershed-based approach to reduce P loading and concentrations as part of the restoration effort. Further studies on other sources of P, currently not regulated by the state or the federal government (e.g., poultry litter), should be conducted as part of the endeavor to restore the Lake Okeechobee watershed and the Everglades.

SUMMARY AND CONCLUSIONS

Although the early BMP programs were effective in reducing P (as well as N) concentrations in runoff from the priority basins, their continuing effectiveness is questionable. Only the S-154 basin exhibited a statistically significant reduction in TP concentrations during the baseline, or post–BMP, period. SRP concentrations in the S-65D basin increased following the implementation of the BMP programs. Additionally, significant increases in inorganic N were observed for the priority basins during the baseline period, with the exception of S-191. Of the four priority basins, S-191 exhibited the greatest decrease in TP concentrations in the pre-BMP period versus the post-BMP period. However, in the post-BMP period, TP concentrations have not been reduced and may be increasing.

The import of municipal residuals and poultry litter during the post-BMP period may have had an influence on the tributary water quality observed in the priority basins. Other activities, such as conversion of land use to higher intensity agricultural production, may also have masked the effectiveness of the BMP programs. New program initiatives, such as the Lake Okeechobee Protection Program and the Comprehensive Everglades Restoration Program, have targeted additional phosphorus control strategies in these four priority basins. A combination of BMPs and public works projects will be implemented to achieve further reductions in phosphorus loads from these basins. Information from this study can be used as the baseline to evaluate the effectiveness of these new initiatives.

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APPENDIX A

Table A-2. Summary Statistics for WY1977-WY1991 (pre-BMPs) Water Quality by Basin

Year	Parameters	No. of Observations	Minimum	Median	Maximum	Mean	Standard Deviation
S-154	Temperature (°C)	90	13.4	24.6	31.2	23.7	4.1
	Specific Conductivity (µmhos/cm)	90	79	254	784	271.5	111.3
	Dissolved Oxygen (mg/L)	88	0.5	2.6	9.1	3.2	2.0
	Water pH	90	5.7	6.4	7.3	6.4	0.3
	Ammonia as N (mg/L)	237	<0.010	0.060	34.010	0.259	2.209
	Nitrate + Nitrite as N (mg/L)	225	<0.004	0.019	1.538	0.047	0.139
	Total Kjeldahl Nitrogen (mg/L)	251	<0.5	2.210	49.520	2.979	3.929
	Total Organic Nitrogen (mg/L)	237	<0.5	2.040	49.350	2.671	3.373
	Total Nitrogen (mg/L)	225	<0.5	2.205	49.545	2.997	4.121
	Soluble Reactive Phosphorus (mg/L)	232	0.143	1.480	10.450	1.796	1.203
	Total Phosphorus (mg/L)	247	0.401	1.732	35.860	2.315	2.761
S-191	Temperature (°C)	340	12.6	23.0	31.9	23.0	3.7
	Specific Conductivity (µmhos/cm)	339	34	366	2840	435.4	310.3
	Dissolved Oxygen (mg/L)	335	0.6	4.2	11.5	4.3	1.8
	Water pH	340	2.0	6.7	8.0	6.7	0.5
	Ammonia as N (mg/L)	3154	<0.010	0.140	19.810	1.035	2.095
	Nitrate + Nitrite as N (mg/L)	3189	<0.004	0.133	12.567	0.537	0.918
	Total Kjeldahl Nitrogen (mg/L)	3188	<0.2	1.870	57.010	3.006	3.762
	Total Organic Nitrogen (mg/L)	3141	<0.2	1.560	54.230	1.957	2.370
	Total Nitrogen (mg/L)	3151	<0.2	2.386	57.258	3.533	3.892
	Soluble Reactive Phosphorus (mg/L)	3060	<0.004	0.625	10.060	0.984	0.989
	Total Phosphorus (mg/L)	3136	0.020	0.819	16.258	1.240	1.280
S-65D	Temperature (°C)	188	9.5	21.7	31.5	21.8	4.0
	Specific Conductivity (µmhos/cm)	186	44	214	722	220.4	82.7
	Dissolved Oxygen (mg/L)	186	1.0	5.0	12.4	5.0	2.0
	Water pH	188	5.4	6.7	7.7	6.7	0.4
	Ammonia as N (mg/L)	701	<0.010	0.020	1.450	0.041	0.112
	Nitrate + Nitrite as N (mg/L)	702	<0.004	0.015	0.627	0.024	0.040
	Total Kjeldahl Nitrogen (mg/L)	714	<0.5	1.360	13.950	1.573	0.987
	Total Organic Nitrogen (mg/L)	700	<0.5	1.335	13.910	1.539	0.961
	Total Nitrogen (mg/L)	701	<0.5	1.380	13.970	1.597	0.996
	Soluble Reactive Phosphorus (mg/L)	703	<0.004	0.067	1.227	0.133	0.187
	Total Phosphorus (mg/L)	707	<0.004	0.121	2.881	0.216	0.284
S-65E	Temperature (°C)	109	10.1	22.8	32.7	23.1	4.4
	Specific Conductivity (µmhos/cm)	109	114	303	1630	510.8	408.4
	Dissolved Oxygen (mg/L)	109	0.5	2.8	10.7	3.2	2.1
	Water pH	109	5.6	6.3	7.9	6.4	0.4
	Ammonia as N (mg/L)	388	<0.010	0.060	2.980	0.190	0.374
	Nitrate + Nitrite as N (mg/L)	377	<0.004	0.022	5.967	0.211	0.521
	Total Kjeldahl Nitrogen (mg/L)	396	<0.5	1.980	52.560	2.665	3.338
	Total Organic Nitrogen (mg/L)	386	<0.5	1.825	52.560	2.412	3.301
	Total Nitrogen (mg/L)	375	<0.5	2.088	52.581	2.804	3.386
	Soluble Reactive Phosphorus (mg/L)	382	<0.004	0.446	7.034	1.164	1.510
	Total Phosphorus (mg/L)	390	0.056	0.782	9.180	1.560	1.801

APPENDIX B

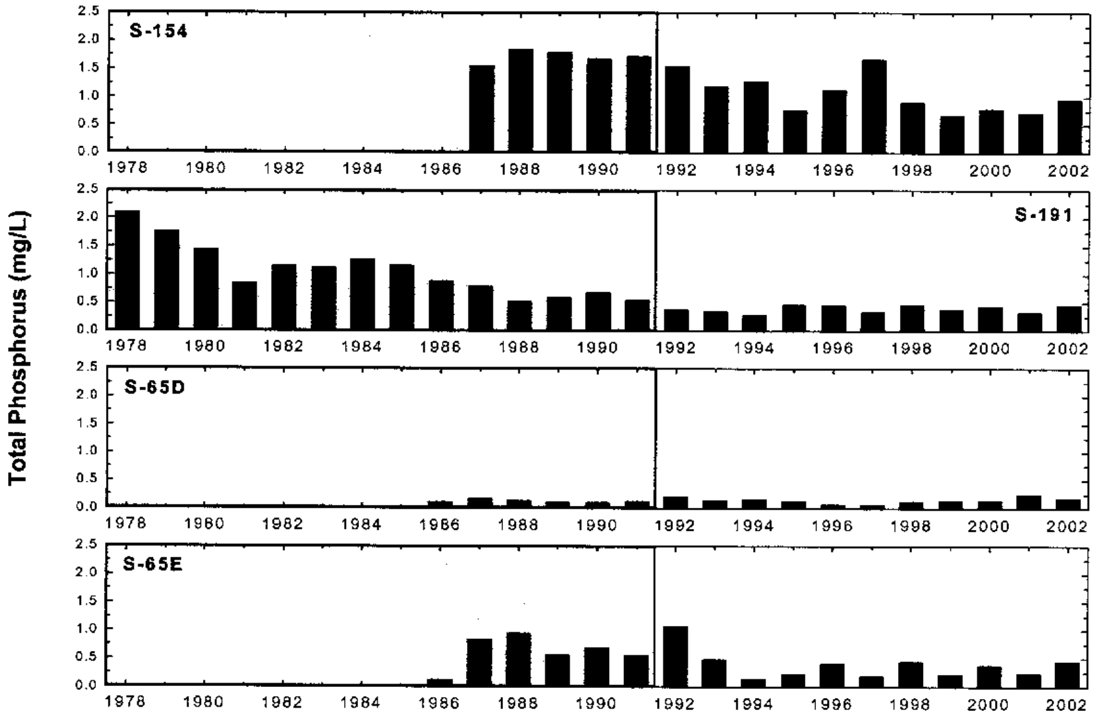


Figure B-1. **Median TP concentrations for the period of record (WY1978 – WY2002). The portions in gray represent the pre-BMP period.**

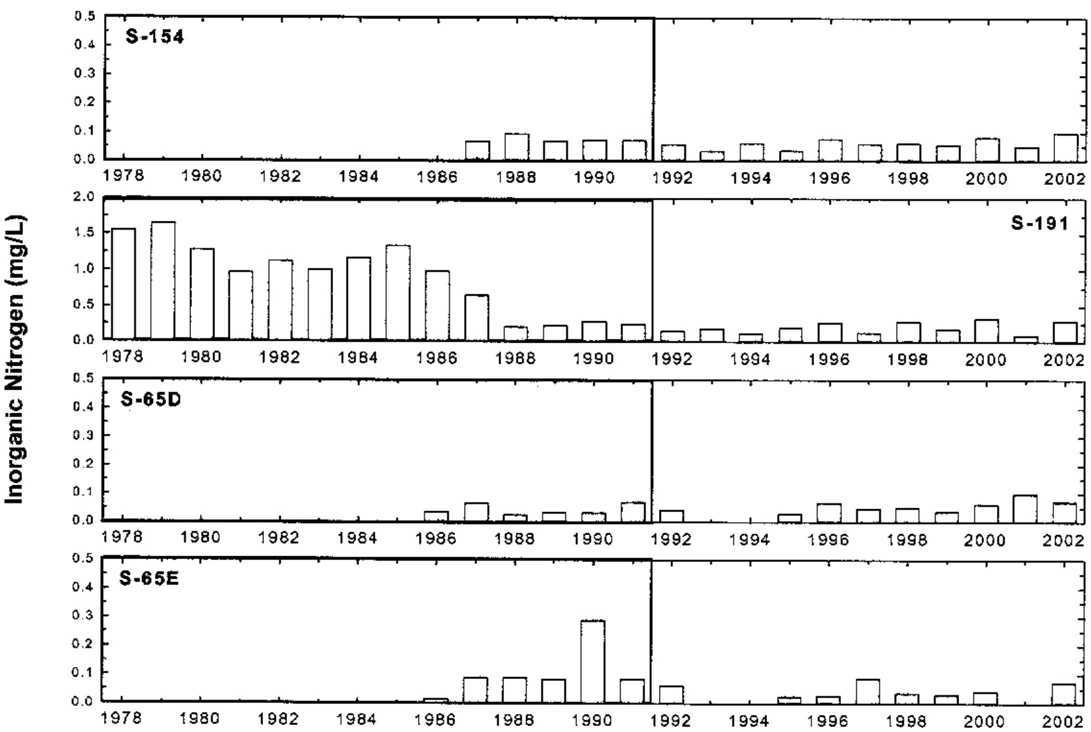


Figure B-2. **Median inorganic N concentrations for the period of record (WY1978 – WY2002). The portions in gray represent the pre-BMP period.**

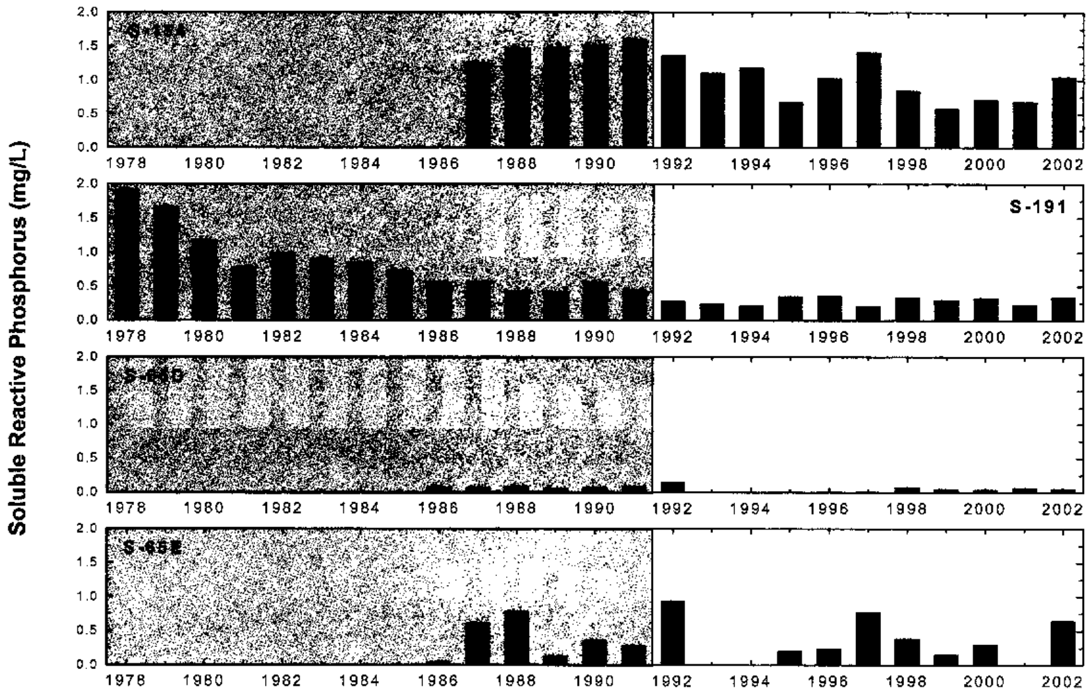


Figure B-3. **Median SRP concentrations for the period of record (WY1978– WY2002). The portions in gray represent the pre-BMP period.**

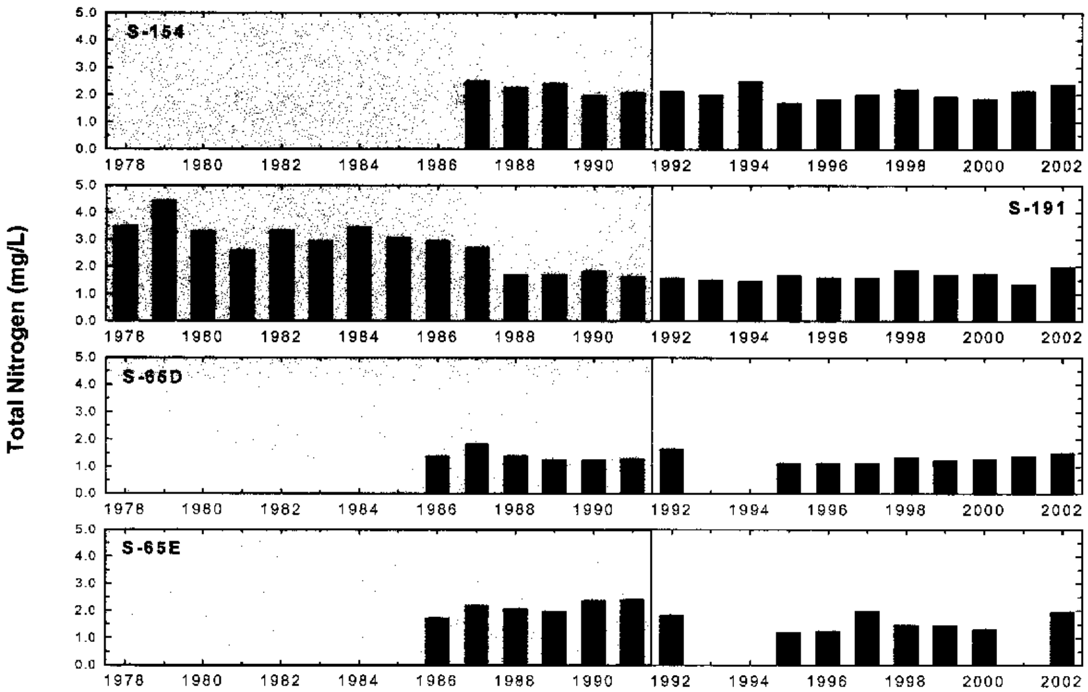


Figure B-4. **Median TN concentrations for the period of record (WY1978 – WY2002). The portions in gray represent the pre-BMP period.**

APPENDIX C

S-191 Basin

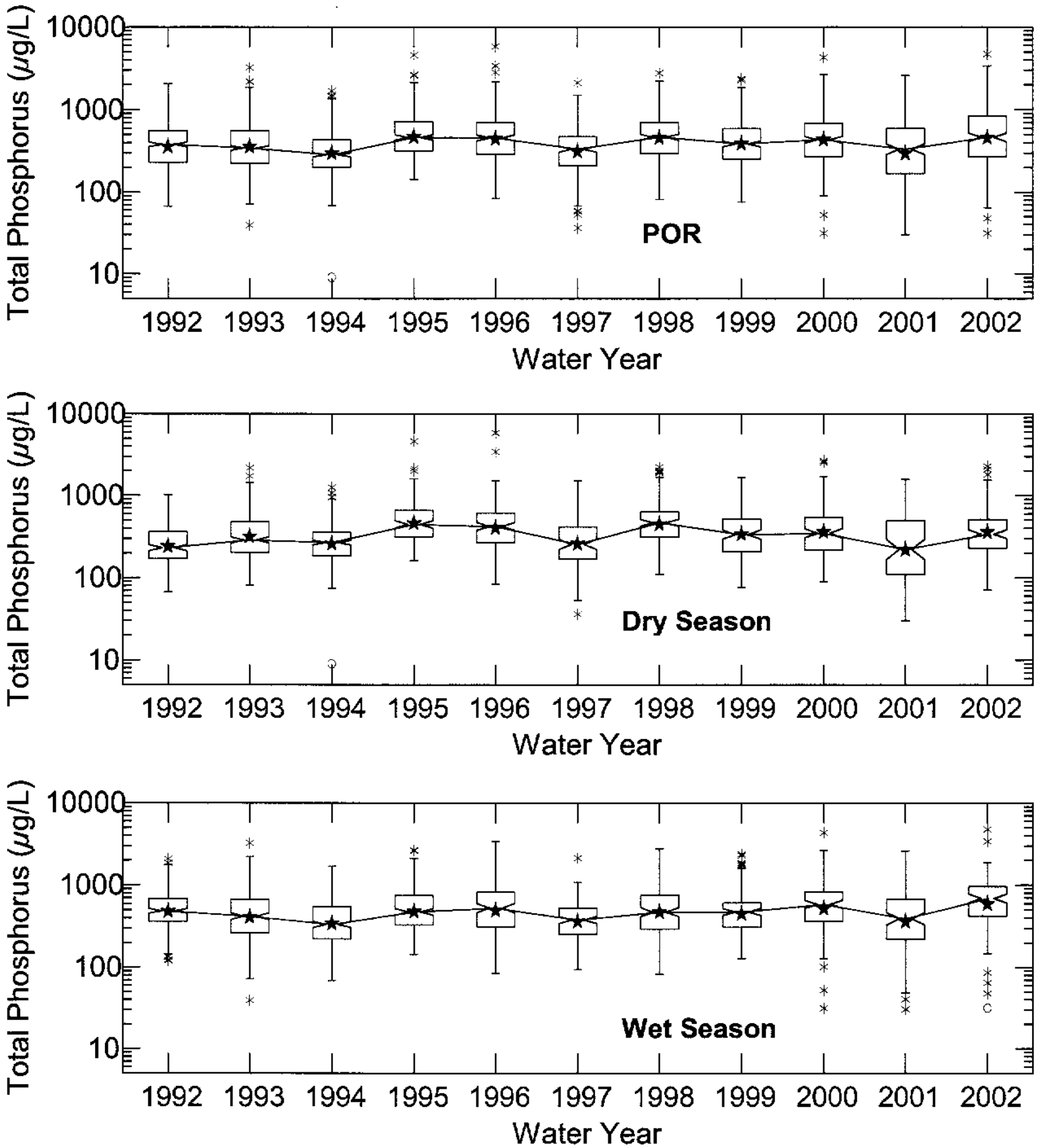


Figure C-1. Notched box-and-whisker plots for median TP concentrations for the baseline period.

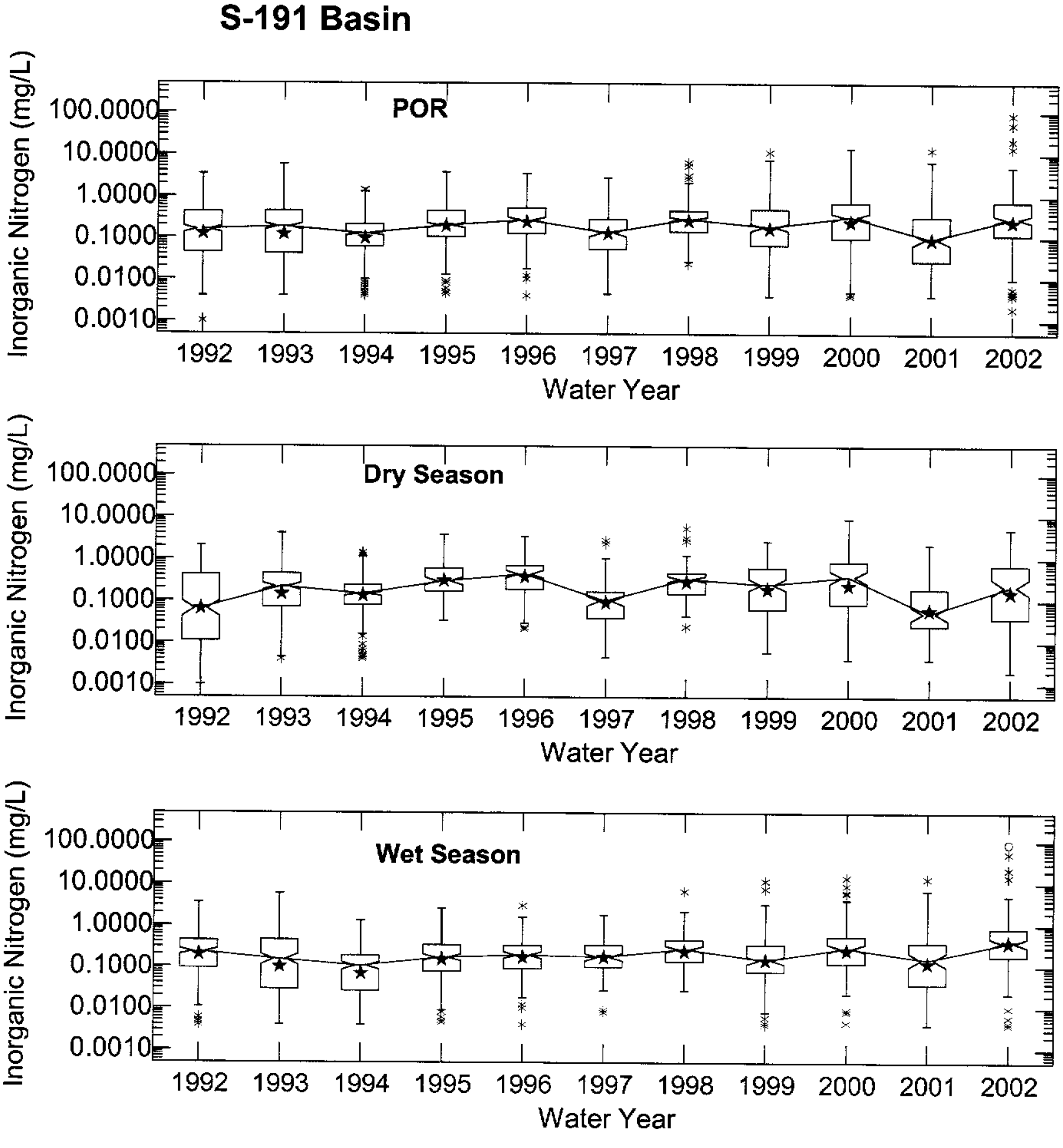


Figure C-2. **Notched box-and-whisker plots for median inorganic N concentrations for the baseline period.**

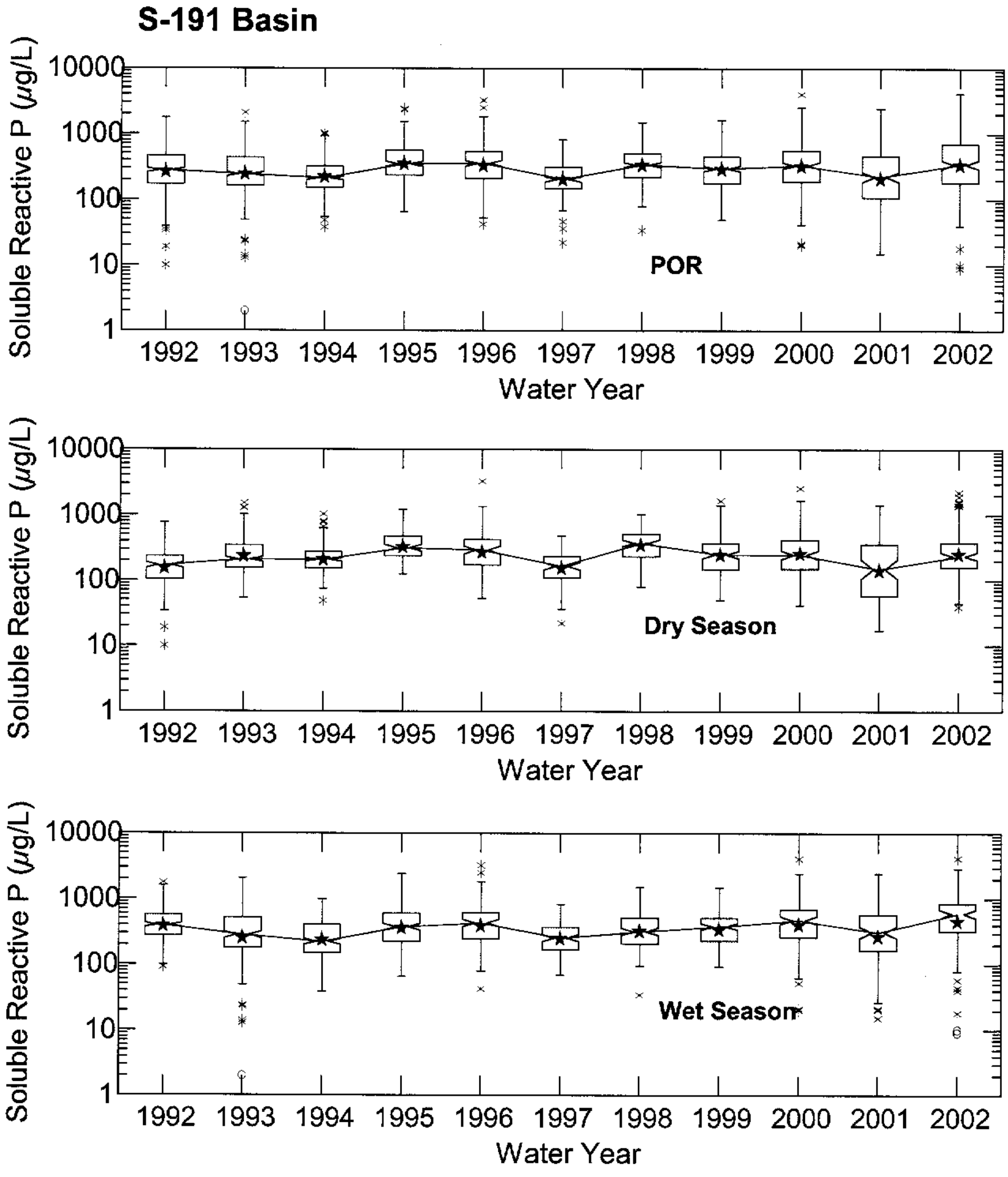


Figure C-3. **Notched box-and-whisker plots for median SRP concentrations for the baseline period.**

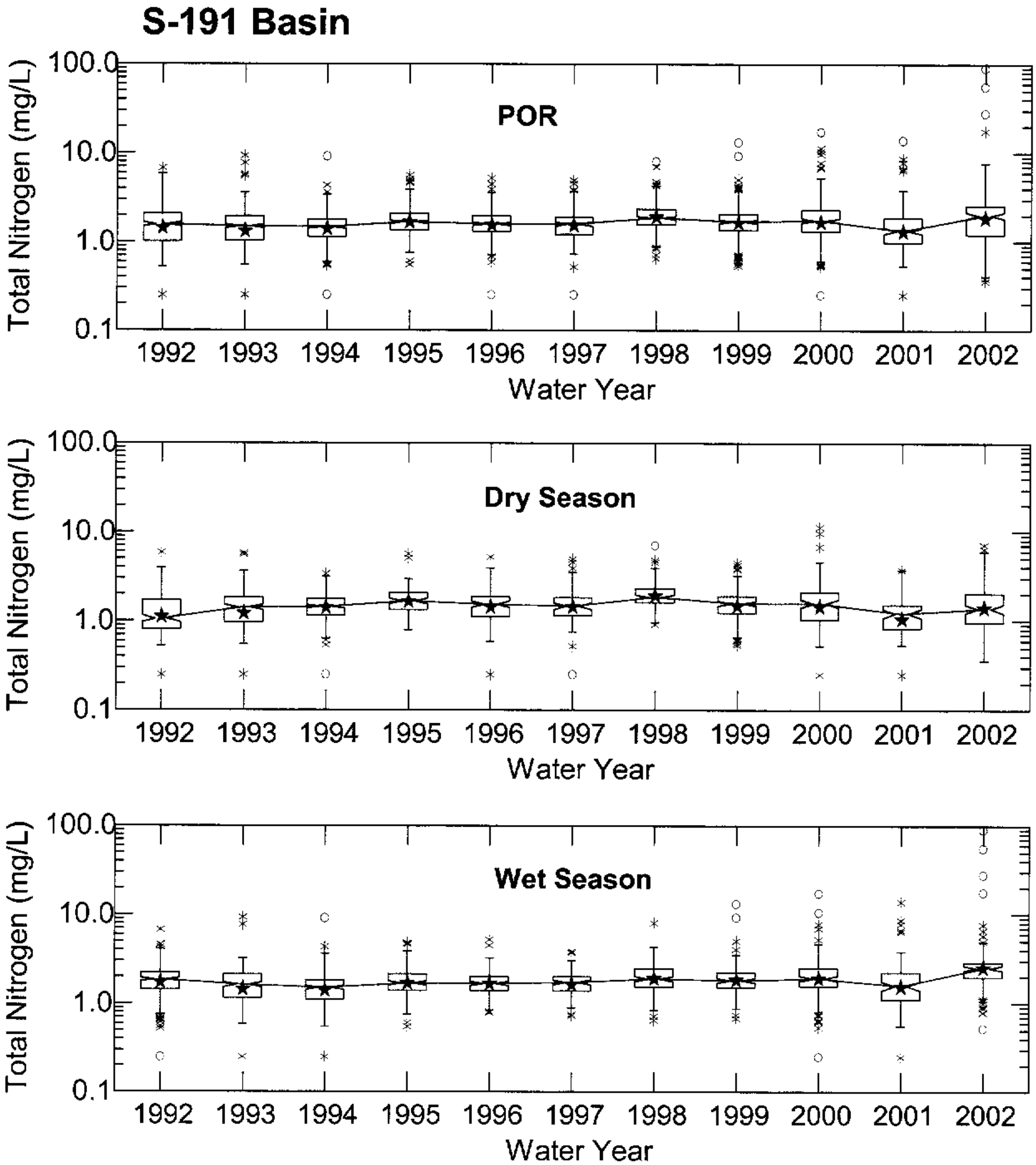
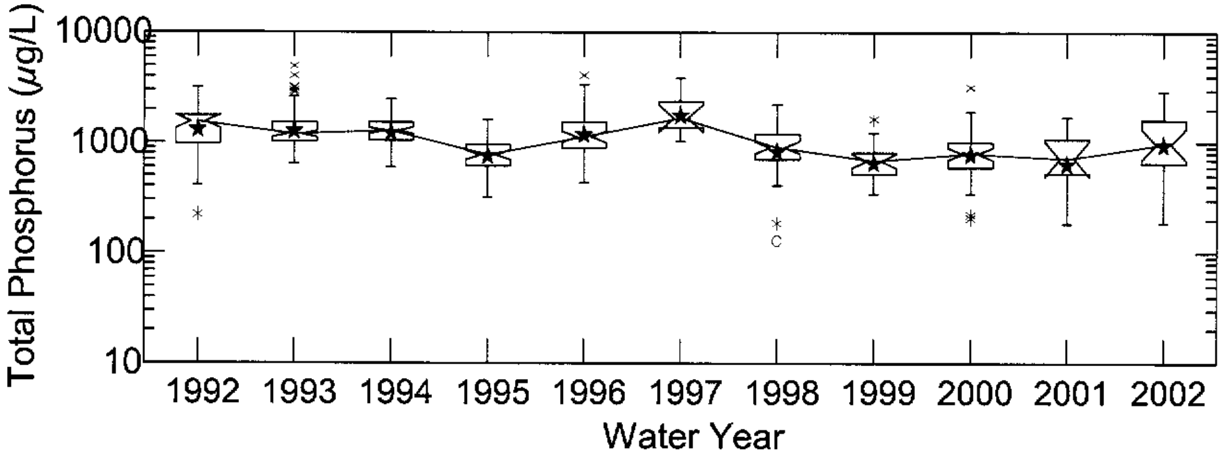
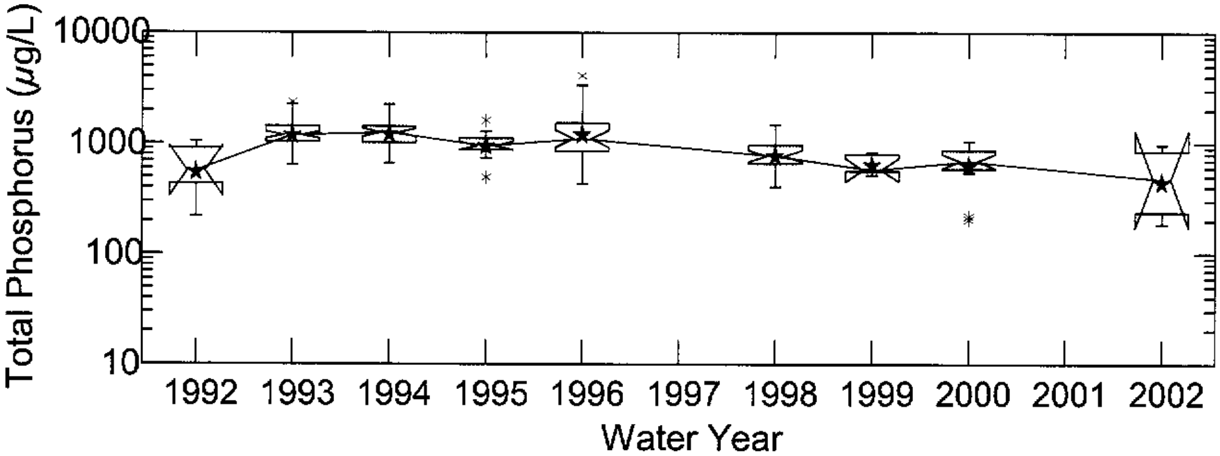


Figure C-4. **Notched box-and-whisker plots for median TN concentrations for the baseline period.**





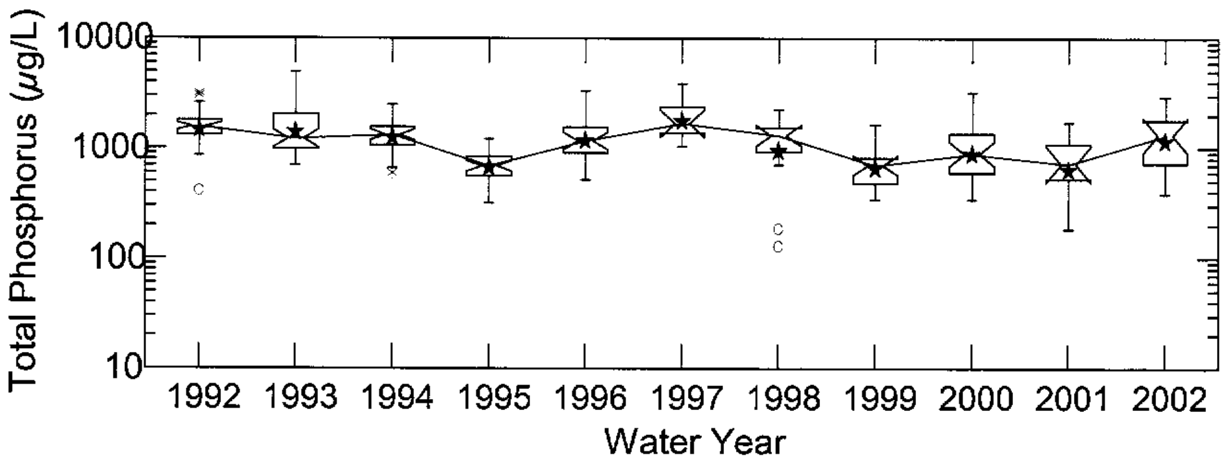


Figure C-5. Notched box-and-whisker plots for median TP concentrations for the baseline period.

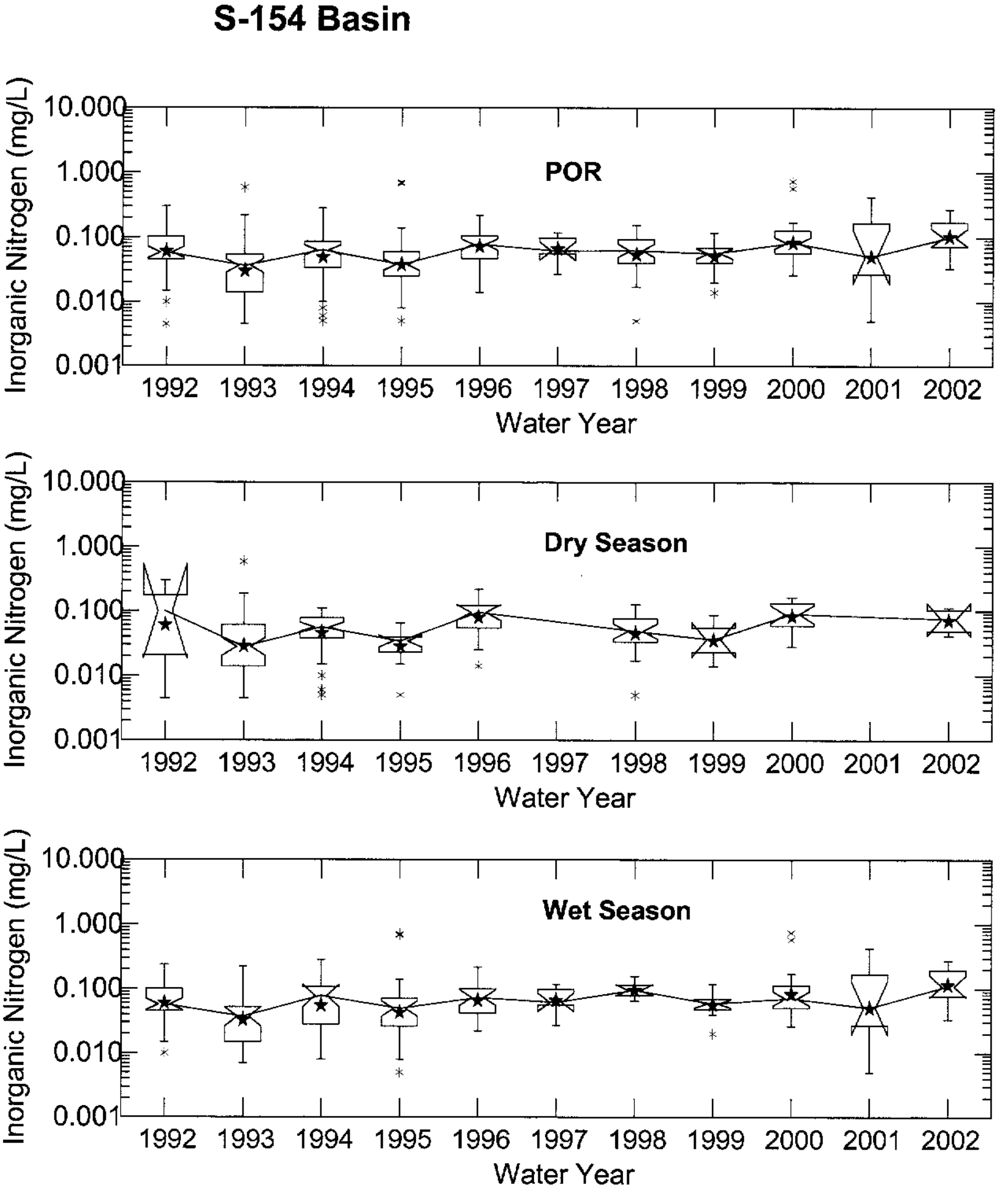


Figure C-6. **Notched box-and-whisker plots for median inorganic N concentrations for the baseline period.**

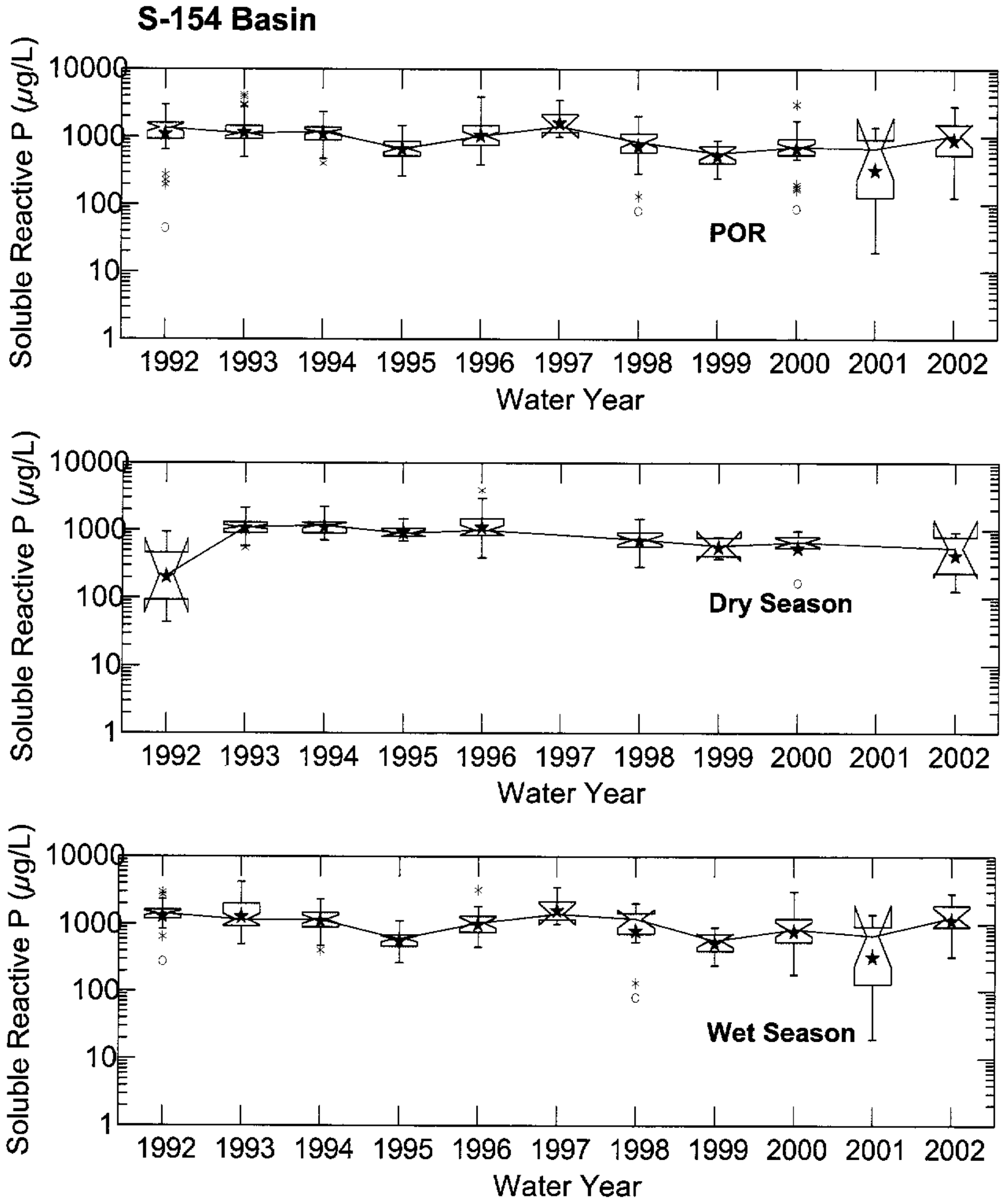


Figure C-7. Notched box-and-whisker plots for median SRP concentrations for the baseline period.

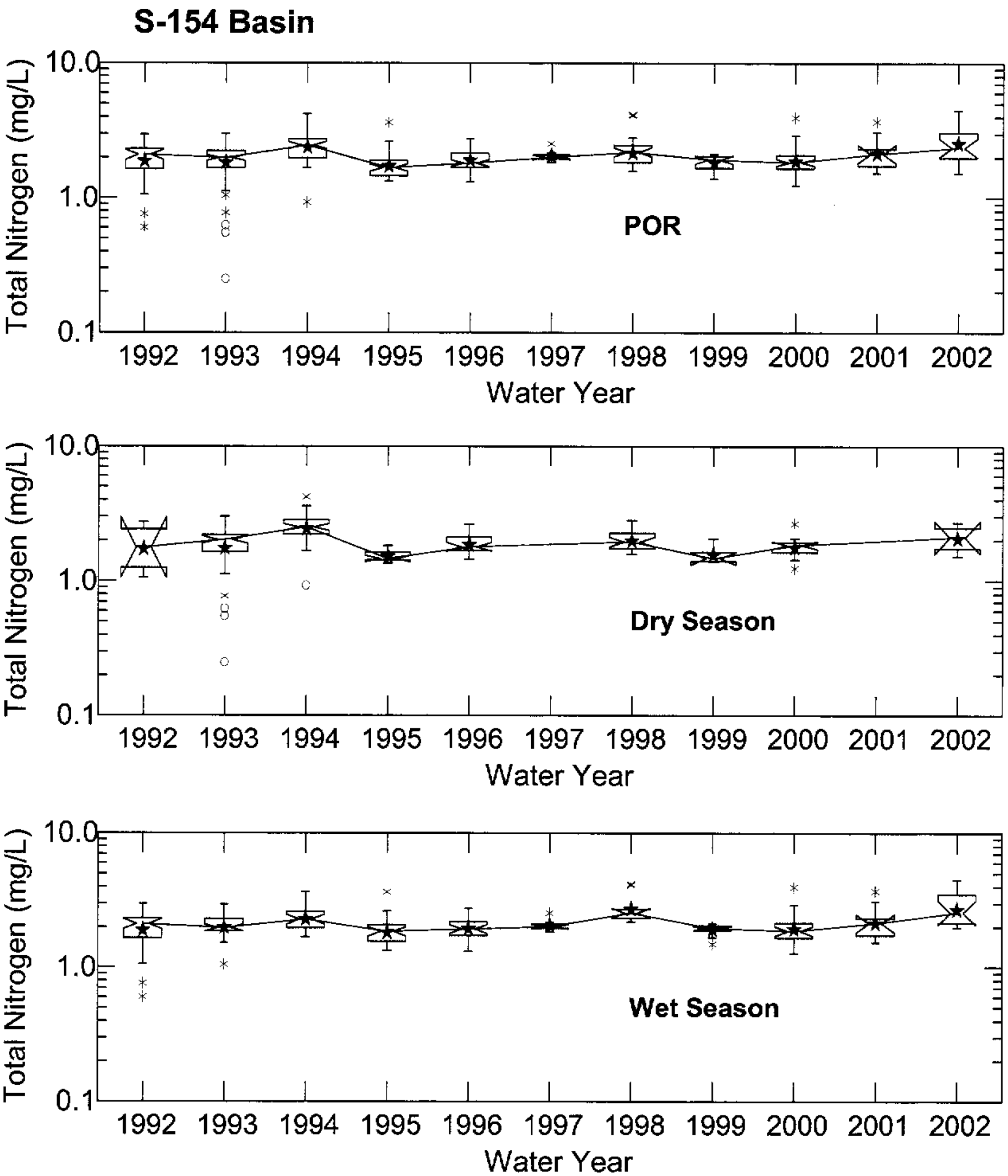


Figure C-8. **Notched box-and-whisker plots for median TN concentrations for the baseline period.**

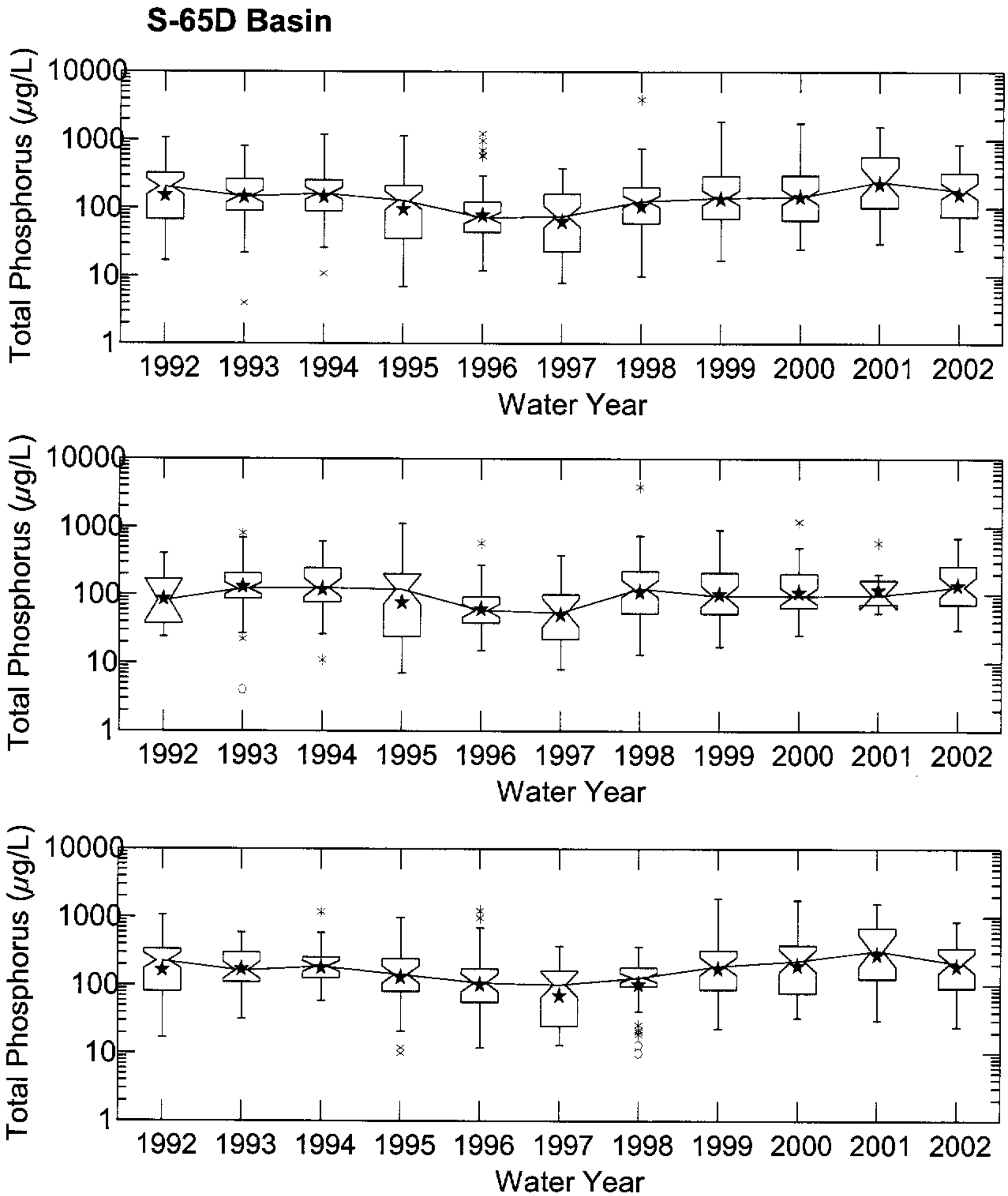


Figure C-9. **Notched box-and-whisker plots for median TP concentrations for the baseline period.**

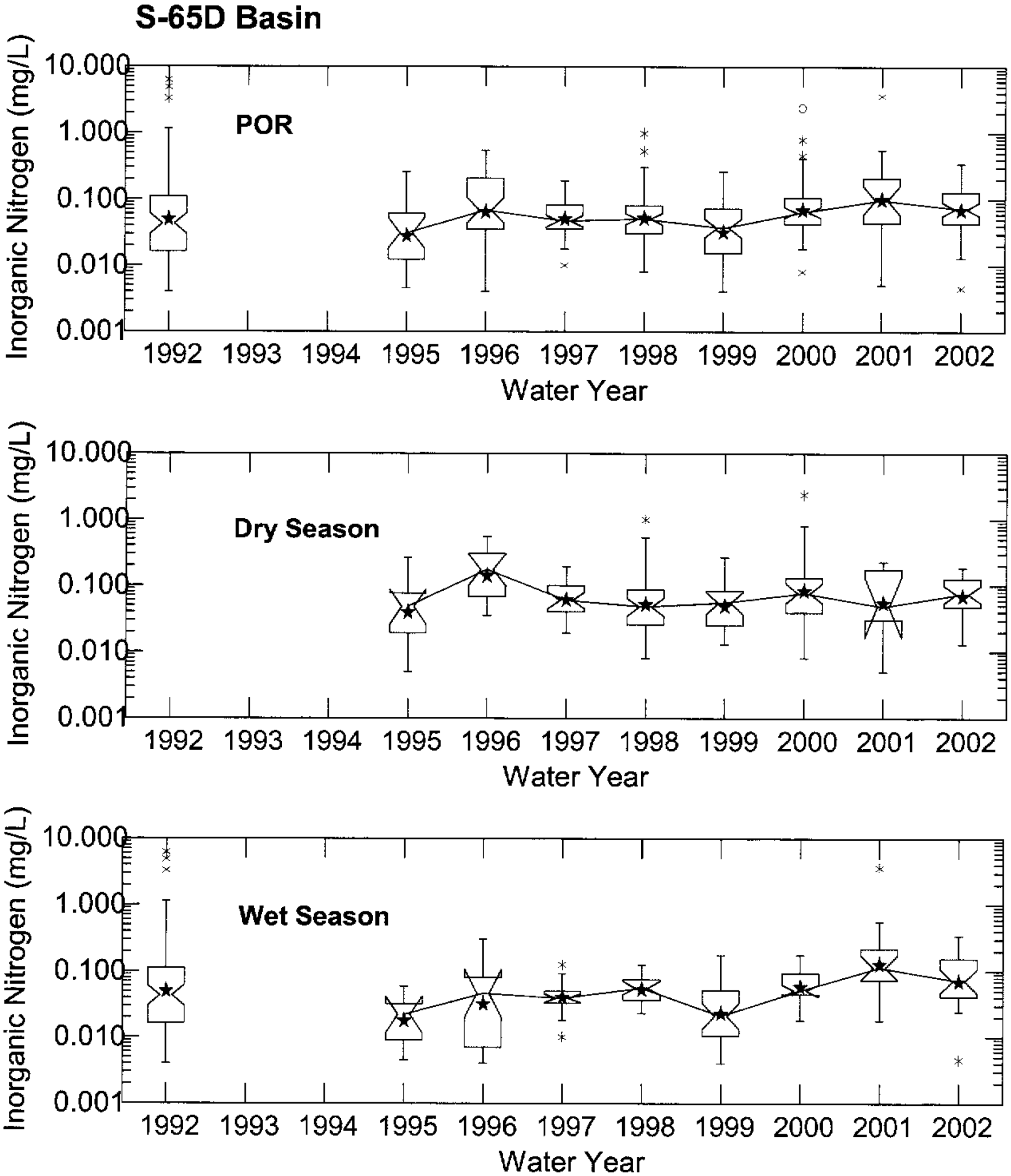


Figure C-10. **Notched box-and-whisker plots for median inorganic N concentrations for the baseline period.**

S-65D Basin

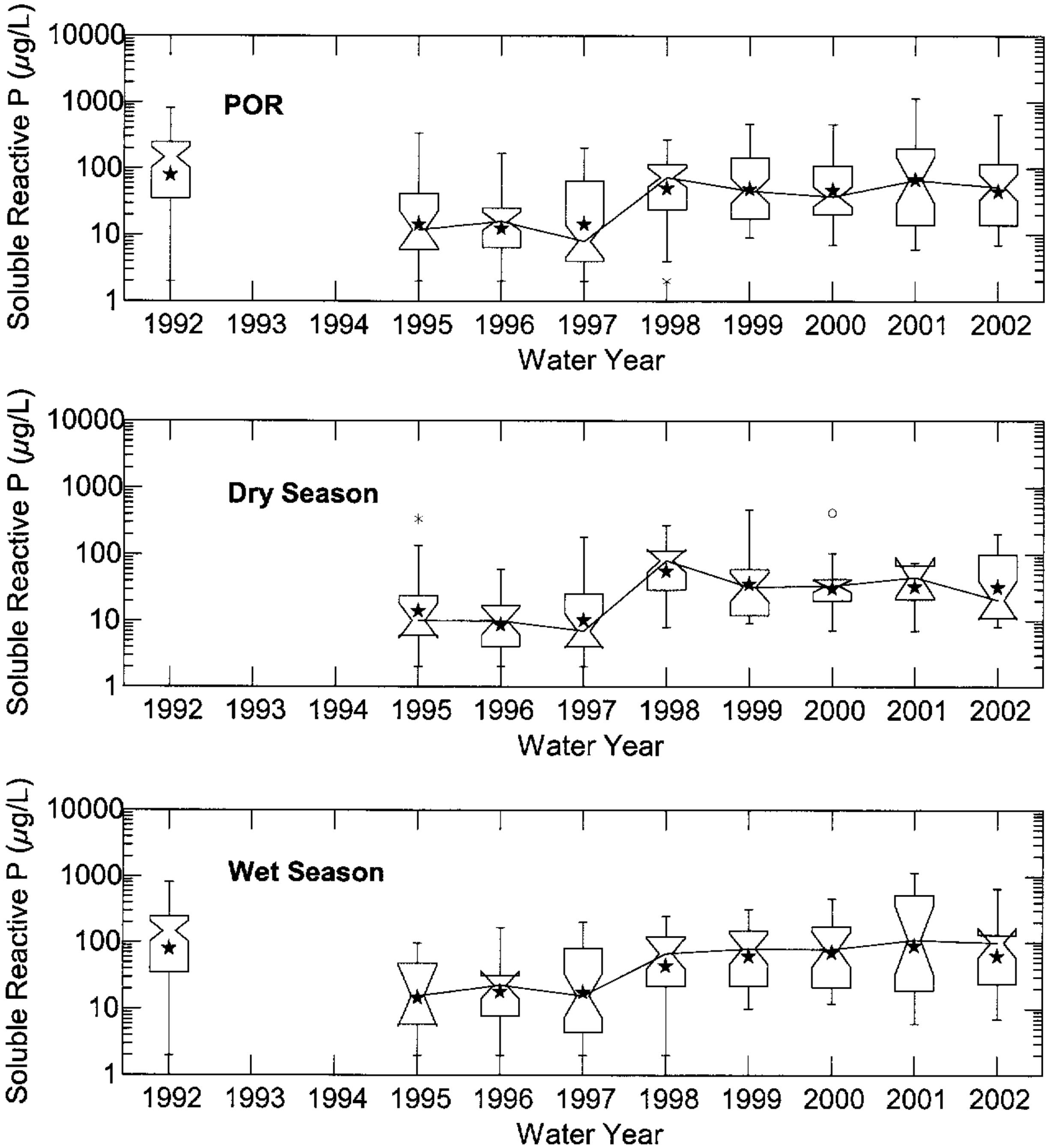


Figure C-11. Notched box-and-whisker plots for median SRP concentrations for the baseline period.

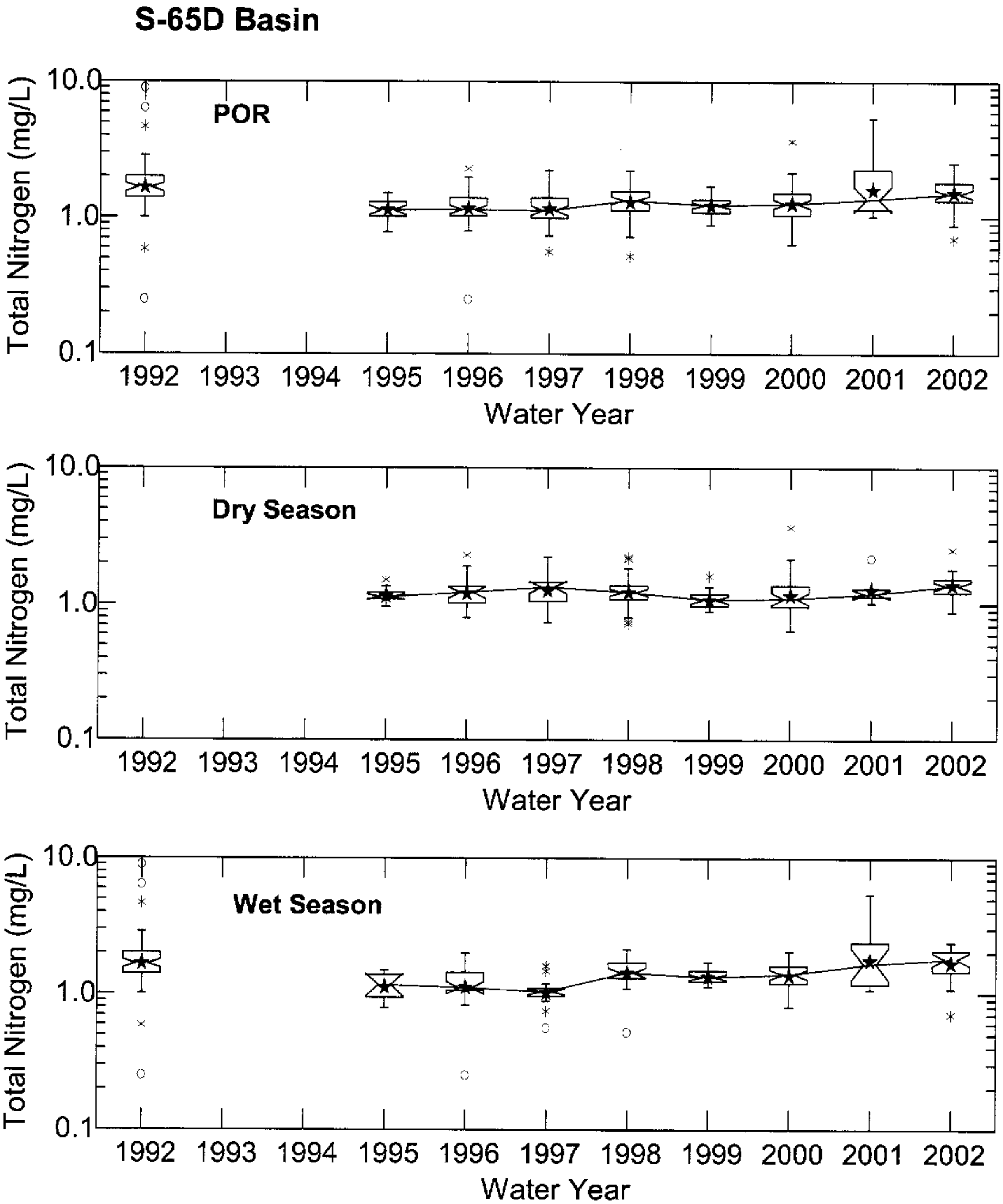


Figure C-12. Notched box-and-whisker plots for median TN concentrations for the baseline period.

S-65E Basin

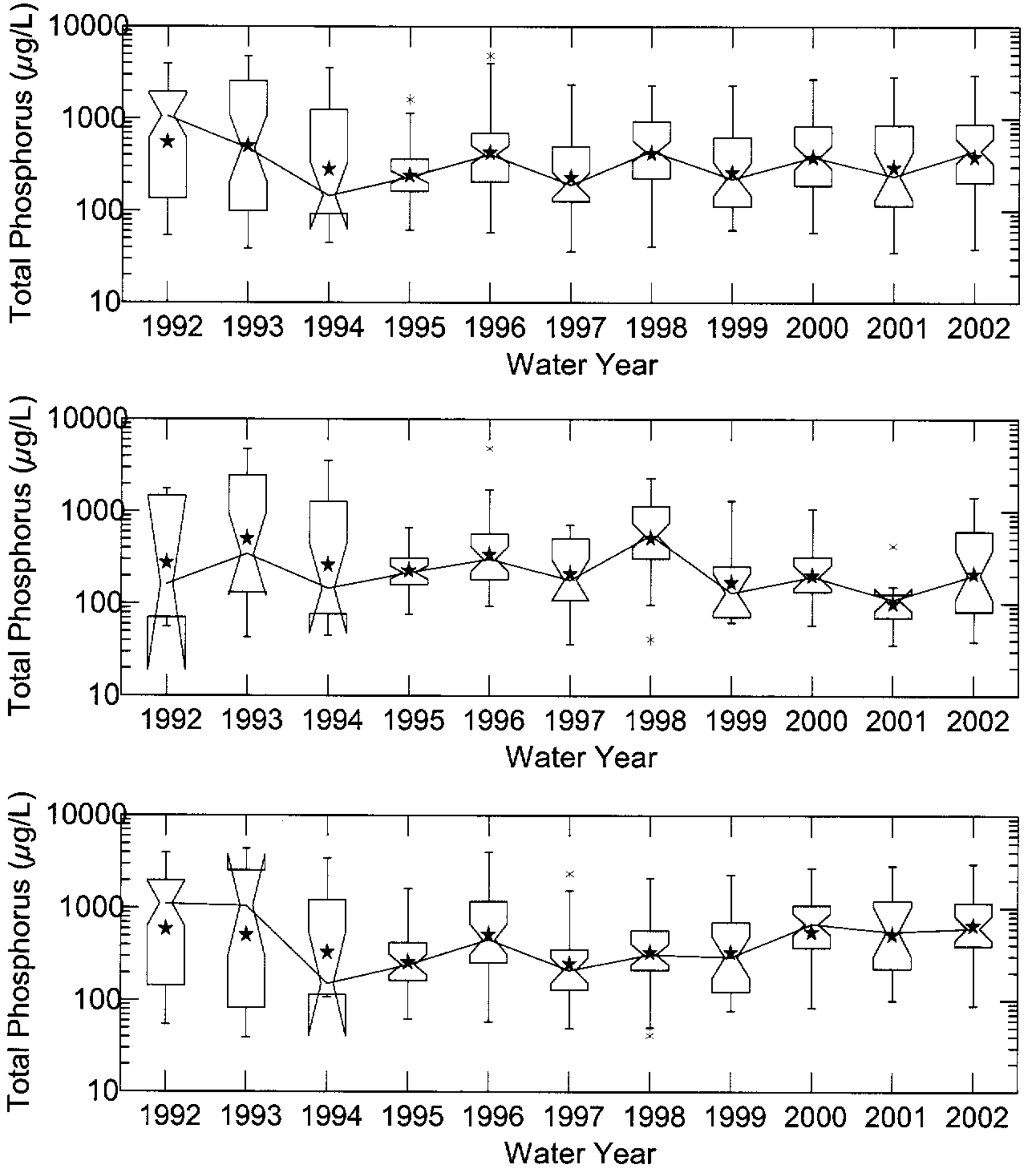


Figure C-13. Notched box-and-whisker plots for median TP concentrations for the baseline period.

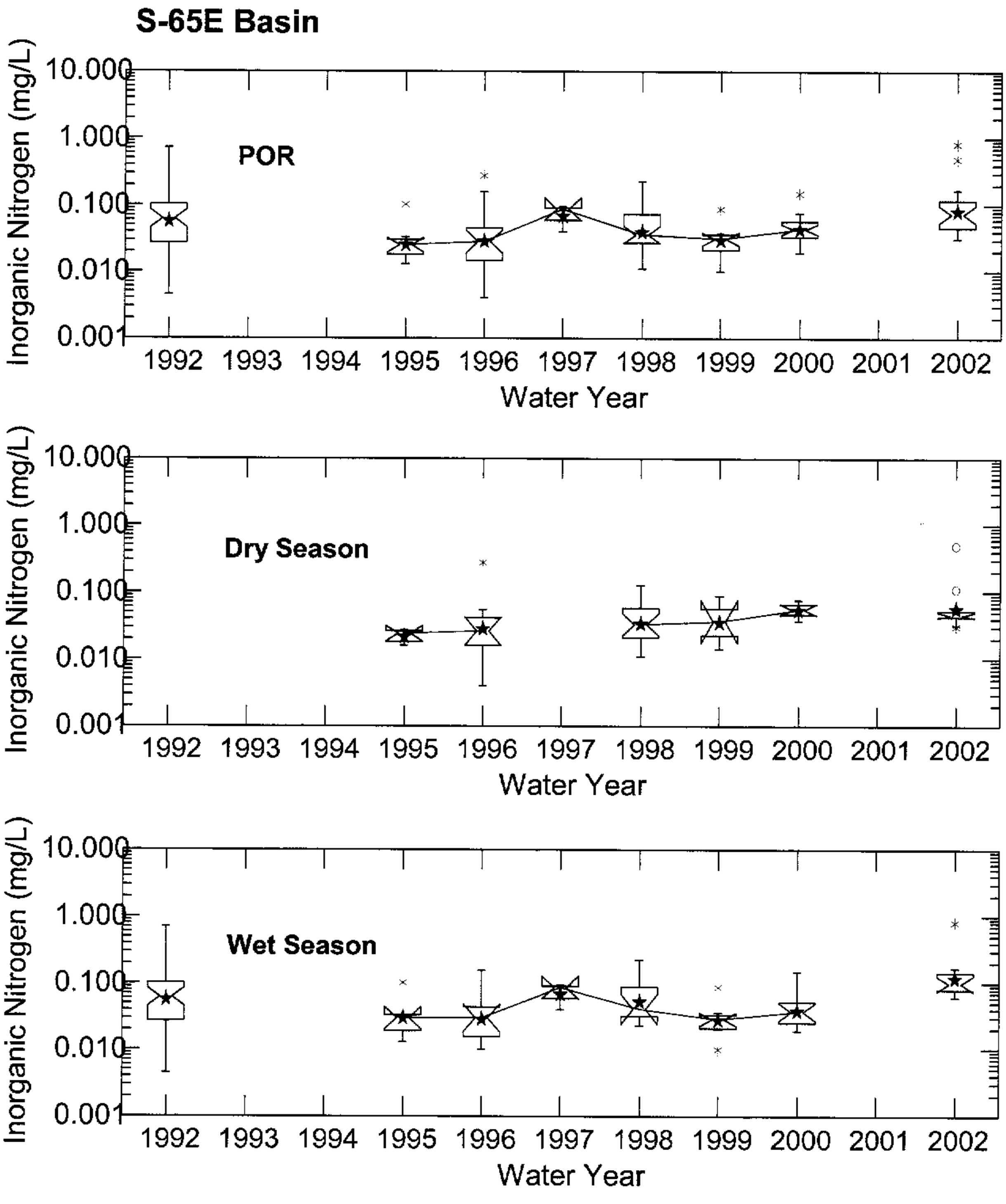


Figure C-14. **Notched box-and-whisker plots for median inorganic N concentrations for the baseline period.**

S-65E Basin

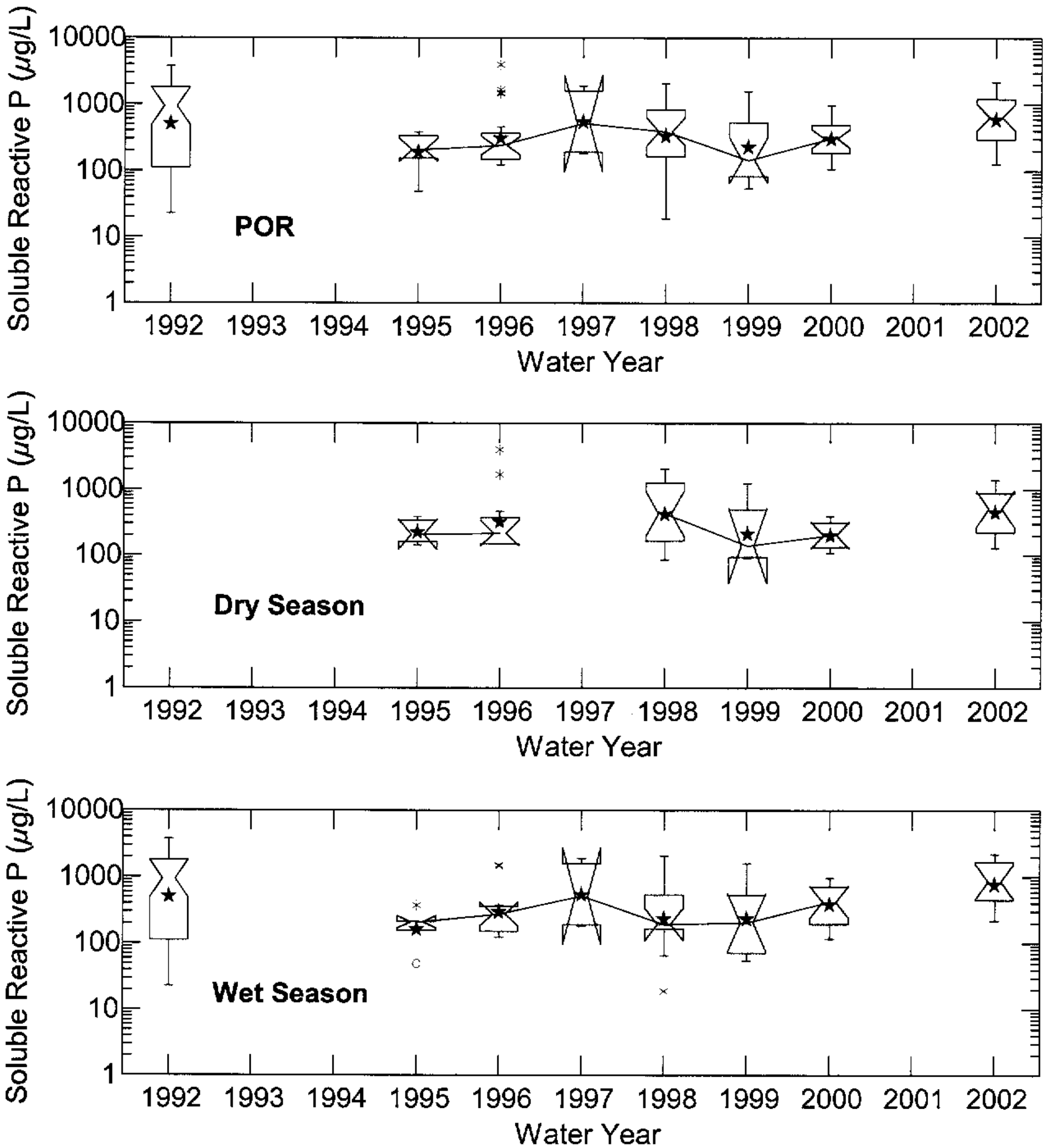


Figure C-15. Notched box-and-whisker plots for median SRP concentrations for the baseline period.

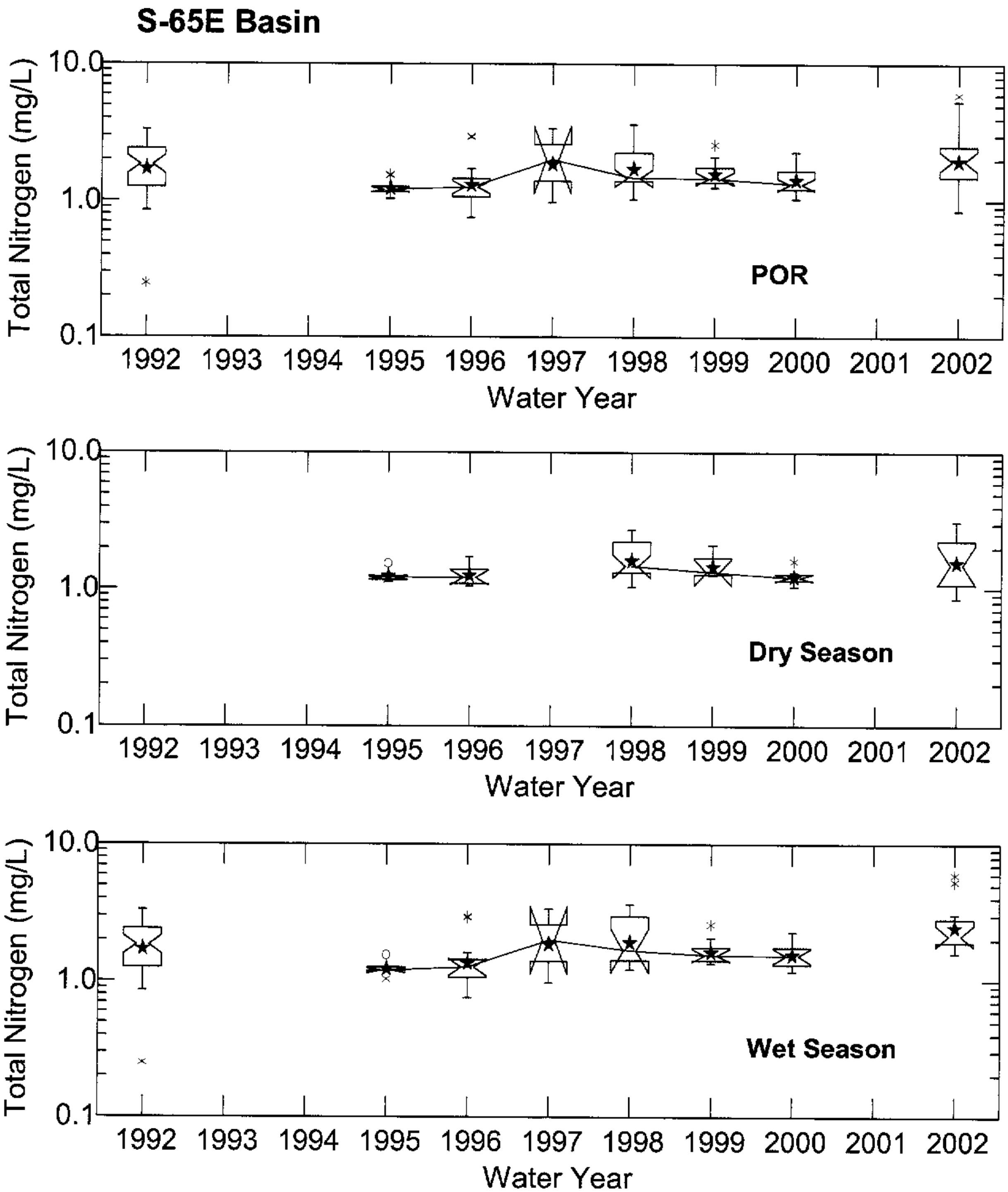


Figure C-16. **Notched box-and-whisker plots for median TN concentrations for the baseline period.**

APPENDIX D

Table D-2. Seasonal Kendall-Tau trend analysis at the monitoring stations in the S-65D basin.

Basin	Station	Parm	Monthly value	Months	Missing Months	Slope	Pvalue
S-65D	KREA01	NNH4	medians	144	53	0.00900	**0.0504**
S-65D	KREA04	NNH4	medians	144	94	0.00600	0.1220
S-65D	KREA06A	NNH4	medians	144	139!	0.00000	1.0000
S-65D	KREA09	NNH4	medians	144	140!	0.00000	1.0000
S-65D	KREA22	NNH4	medians	144	63	0.00425	0.4878
S-65D	KREA23	NNH4	medians	144	77	0.00278	0.2442
S-65D	KREA01	SRP	medians	144	51	0.00708	0.2048
S-65D	KREA04	SRP	medians	144	94	0.00913	0.1120
S-65D	KREA06A	SRP	medians	144	139!	0.00000	1.0000
S-65D	KREA09	SRP	medians	144	140!	0.00000	1.0000
S-65D	KREA22	SRP	medians	144	55	0.00093	0.3178
S-65D	KREA23	SRP	medians	144	71	0.00133	**0.0295**
S-65D	KREA01	TOTN	medians	144	52	0.04100	**0.0140**
S-65D	KREA04	TOTN	medians	144	94	0.09300	0.0845
S-65D	KREA06A	TOTN	medians	144	139!	0.00000	1.0000
S-65D	KREA09	TOTN	medians	144	140!	0.00000	1.0000
S-65D	KREA22	TOTN	medians	144	62	0.02667	0.1881
S-65D	KREA23	TOTN	medians	144	76	0.04477	0.0966
S-65D	KREA01	TPO4	medians	144	23	0.00994	**0.0440**
S-65D	KREA04	TPO4	medians	144	60	0.00114	**0.5386**
S-65D	KREA06A	TPO4	medians	144	29	0.00850	0.2161
S-65D	KREA09	TPO4	medians	144	86	0.04218	**0.0445**
S-65D	KREA22	TPO4	medians	144	54	0.00200	0.1917
S-65D	KREA23	TPO4	medians	144	70	0.00885	**0.0040**

! Insufficient Data

Bolded numbers: Statistically Significant

Note: The P values have been adjusted for significant serially correlated data.

APPENDIX 4

LAKE OKEECHOBEE PROTECTION PROGRAM
LAKE RESTORATION ASSESSMENT PLAN

Lake Okeechobee Protection Program (LOPP)

Lake Restoration Assessment Plan

Project Leader: Dr. Karl E. Havens, South Florida Water Management District, Telephone: (561)-682-6534, E-mail: khavens@sfwmd.gov

LOPP Coordinating Agencies:

South Florida Water Management District, Florida Department of Agriculture and Consumer Services, Florida Department of Environmental Protection

Table of Contents

I. Executive Summary

The purpose of this document is to describe a restoration assessment program for Lake Okeechobee, specifically designed to support the Lake Okeechobee Protection Program (LOPP), with applicability to the Comprehensive Everglades Restoration Program (CERP). This document includes:

(1) a conceptual model of the Lake ecosystem that is the basis of the program;
(2) an overview of two decades of science that led to development of the conceptual model;
(3) a set of quantitative performance measures that will be used to evaluate restoration success; and
(4) methods that will be used to evaluate the performance measures, archive the information, and present summary results to decision makers and the general public.

The focus of this **Lake Restoration Assessment Plan** is on the Lake itself, rather than on the entire watershed, as the Lake is the natural resource that we are attempting to "restore" by carrying out the various projects of the LOPP. A similar, performance measure-based document for the Lake Okeechobee watershed will be developed.

The conceptual model for Lake Okeechobee was modified from an earlier version (Havens 2000) that was developed as part of the CERP Restudy process. The model in this Plan is simplified, and focuses only on those aspects of the ecosystem expected to be directly affected by the LOPP and CERP projects. The model identifies three main stressors: excessive ***phosphorus loads***, unnatural high and low ***lake stage***, and ***invasive plants***, that have been identified in past research as causing serious imbalances in native flora and fauna of the ecosystem. The model identifies two ecological / societal values of the resource that LOPP aims to protect and enhance: ***water quality*** (for drinking, recreation, and support of natural flora and fauna) and ***fish and wildlife*** (including sport fish, commercial fish, and wading birds). At the core of the model are a set of ecological processes that link the stressors to values. For example, high lake stage stimulates the transport of resuspended mud sediments from mid-lake to shallow shoreline areas, which reduces light availability to submerged plants, leading to a decline in their biomass. This, in turn, results in less uptake of phosphorus from the water by plants, increased algal blooms, and deteriorated water quality for drinking and other uses. A variety of ecological processes of this type are described in the Plan, which also provides references to the peer-reviewed science that supports those concepts. Key areas of uncertainty also are identified, as focal points for future LOPP supported research.

A total of 20 ecosystem performance measures are identified in the Plan, in order evaluate success of the LOPP in restoring the health of Lake Okeechobee. These include 3 hydrologic measures (occurrence of extreme high and low stage, and spring stage recessions), 10 water quality measures (total phosphorus loads, pelagic, near-shore, and littoral zone total phosphorus, total nitrogen: phosphorus ratios, limiting nutrient status of the lake, diatom: blue-green algae ratio, algal bloom frequency, water clarity, and Class I water quality parameters), and 7 biological measures (submerged aquatic vegetation, emergent vegetation, exotic vegetation, plankton food web efficiency, invertebrates and forage fish, sport fish, and shoreline organic berm accumulation). For each of these performance measures, quantitative restoration targets have been established, or will be established in the near future as additional information becomes available.

A comprehensive hydrologic and water quality monitoring program has been carried out by the South Florida Water Management District (SFWMD) since the early 1970s on Lake Okeechobee. Data from this ongoing program will be used to track progress toward targets for the hydrologic and water quality performance measures. Since the mid-1990s, the Lake Okeechobee Division of the SFWMD has been developing a comprehensive program to monitor the biological performance measures identified in this Plan. That program, along with ongoing work by the Florida Fish and Wildlife Conservation Commission, will provide the data required to evaluate progress toward biological targets.

Data collected under this assessment Plan will be archived in the SFWMD water quality database and in the Lake Okeechobee Ecological Database, which will be web-enabled to allow for user-friendly access by other agencies and the general public. The results of this program also will be used to generate a "report card" that summarizes health of the Lake Ecosystem and responses to restoration projects, in terms of the quantitative performance measures. This report card will be used to update the Florida Legislature, the SFWMD Governing Board, and the general public, on status and trends in the Lake ecosystem, perhaps at 3 to 5 year intervals. Example report card pages are included in this document for pelagic (open-water) total phosphorus and submerged aquatic vegetation.

Development and refinement of this Plan will, by necessity, be an iterative process. As new information becomes available based on additional research, periodic reviews and revisions of the Plan will ensure continued technical rigor and the opportunity for continued input from the coordinating agencies.

II. Introduction

This document is the first draft of a Lake Restoration Assessment Plan for the Lake Okeechobee Protection Program (LOPP). Projects implemented under the LOPP are expected to substantially improve water quality and ecological conditions in the Lake. LOPP projects also will contribute, in part, to improved hydrologic conditions, which primarily are being implemented by projects under the Comprehensive Everglades Restoration Program (CERP). The Lake Restoration Assessment Plan (hereafter, the Plan) establishes a framework for measuring responses of the ecosystem to the LOPP.

The purpose of the Plan is to describe a monitoring and assessment program that will allow the coordinating agencies to evaluate progress towards clearly defined targets for a number of science-based performance measures for the Lake Okeechobee ecosystem. Performance measures are specific elements of the natural system that are selected to quantitatively identify and describe the restoration targets and expectations of the LOPP, consistent with the objectives that the LOPP is authorized and designed to meet. Long-term assessment of the elements identified by the performance measures is the principal means for determining how well the LOPP achieves its goals and objectives. This process mirrors that currently under development by the Restoration Coordination and Verification (RECOVER) program of CERP. The Plan is designed to optimize the collection of essential information, and to take advantage of any overlap in restoration evaluation needs for CERP and the LOPP. Many of the Lake performance measures described in the Plan also will be used to evaluate restoration success in CERP.

The key feature of the Plan is that it is based on over 20 years of rigorous scientific research on Lake Okeechobee and other similar shallow lake ecosystems. The results of that research were used to formulate an ecosystem conceptual model that describes major linkages between stressors and natural / societal values of the water resource. The model serves as the basis for performance measures, ecosystem monitoring, and prioritization of future research. The details of this model are presented in Section III of the Plan. The model is based on a framework (Havens 2000) that was developed with input from scientists and engineers at the South Florida Water Management District (SFWMD), Florida Department of Environmental Protection (FDEP), Florida Fish and Wildlife Conservation Commission (FWC), US Environmental Protection Agency (USEPA), and US Fish and Wildlife Service (USFWS). Staff from these agencies and organizations also contributed to development of hydrologic, water quality, and biological performance measures that are reflected in this Plan.

Development and refinement of the Lake Restoration Assessment Plan will, by necessity, be an iterative process. As new information becomes available, periodic reviews and revisions of the Plan (including expert peer review) will ensure continued technical rigor and the opportunity for continued input from the coordinating agencies.

II. Lake Okeechobee Conceptual Model

The purpose of a conceptual ecosystem model is to illustrate major links between environmental stressors and natural / societal values in an ecosystem. Ecosystem conceptual models have been widely used as planning tools for restoration projects and in ecological risk-assessment (e.g., Harris et al. 1995, Trexler 1995, Gentile et al. 2001). In general, they are designed to meet the following purposes:

(1) show the ecological links between the physical, chemical, and biological elements in the natural system;

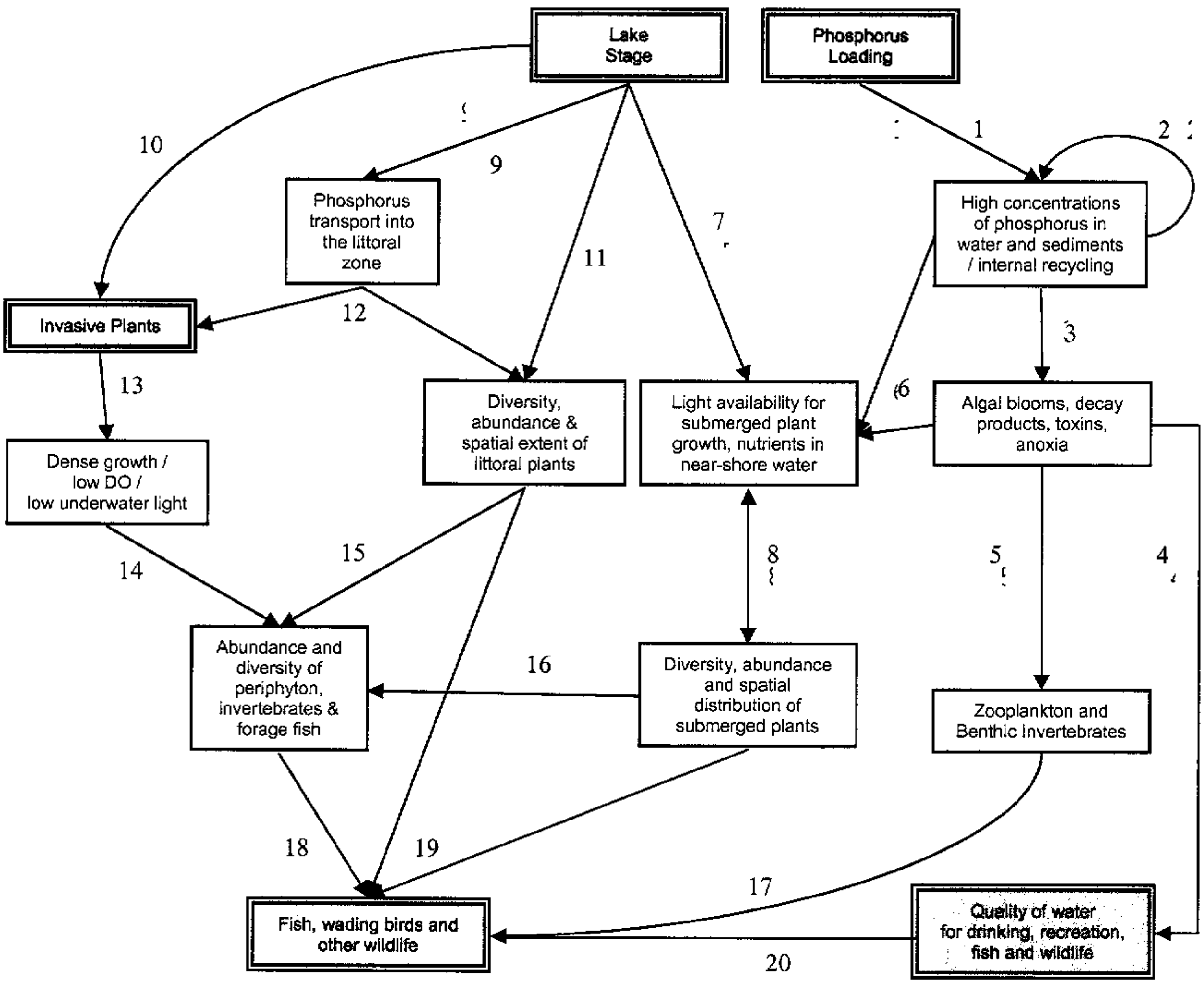
(2) develop a set of explanations linking key stressors with the major ecological / societal values, as a basis for predicting responses to restoration program actions; and

(3) create a set of measurable indicators of success as a basis for evaluating how well the restoration program meets its stated goals.

The conceptual model provides the scientific basis for the development of the restoration assessment process. The modeling process makes it possible to convert overall restoration goals (e.g., restore the health of the lake) into specific performance measures that can be used to plan, design, and assess the overall restoration program.

In the conceptual model for Lake Okeechobee, there are three major ecosystem stressors: ***excessive phosphorus loads***, ***invasive plants***, *and extreme variations in* ***lake stage***. There are two major natural / societal values: ***fish and wildlife*** (e.g., habitat for migratory water fowl and wading birds, recreational and commercial fishing, ecotourism) and ***water quality*** (e.g., for drinking water, as well as the appropriate water quality for fish and wildlife). A complex set of ecological processes link the stressors and values (**Figure 1**). The model integrates existing information about the ecosystem and provides a technical foundation for performance measures and the monitoring & assessment. Therefore, it is important to review, in detail, the various concepts included in this model, prior to introducing those other aspects of the Plan. The following overview considers, in sequence, background information about the Lake, major ecosystem stressors, key ecosystem values, and ecological effects that link the stressors to the values.

Figure 1. Lake Okeechobee conceptual model, showing three major stressors (boxes with double borders at top), two major ecological / societal values (boxes with double borders at bottom), and major ecological processes linking stressors with values (boxes with single borders). Arrows are major concepts (working hypotheses) about how the stessors affect the values. This model is adapted from Havens (2000) and focuses on stressors expected to be directly affected by the LOPP. The numbers correspond to working hypotheses described in the text.



III.1 Background Information

Lake Okeechobee is a large (1,730 km^2) freshwater lake located at the center of the interconnected south Florida aquatic ecosystem. The lake is shallow (average depth <3 m), originated about 6,000 years ago during oceanic recession, and under natural conditions probably was slightly eutrophic and had vast marshes to the west and south (Havens et al. 1996a). The southern marsh was contiguous with the Florida Everglades, which received water as a broad sheet flow from the lake during periods of high rainfall (Gleason 1984). Modern-day Lake Okeechobee differs in size, range of water depths, and connections with other parts of the regional ecosystem (Steinman et al. 2001). Construction of the Herbert Hoover Dike in the early to mid-1900s reduced the size of the lake's open-water zone by nearly 30%. This resulted in a considerable reduction in average water levels, and produced a new littoral zone within the dike that is only a fraction of size of the natural one. The lake has been impacted in recent decades by excessive inputs of phosphorus from agricultural activities in the watershed (Flaig and Havens 1995, Havens et al. 1996a). These nutrients have exerted the most dramatic impacts on the open-water region, where large algal blooms have occurred, along with accumulation of soft organic mud bottom sediments, which cause the lake water to become highly turbid when they are resuspended during windy periods (Maceina and Soballe 1991). The littoral zone has been invaded by 15 species of exotic plants, most notably *Melaleuca quinquenervia* and *Panicum repens* (torpedo grass), which have expanded over large areas, displacing native plants. Despite these human impacts, and a consensus that the lake's overall health has been greatly degraded by human actions, Lake Okeechobee continues to be a vital aquatic resource of south Florida, with irreplaceable natural and societal values. The major expectation of the LOPP and CERP is that they will improve the water quality and hydrologic conditions in the Lake, and that this will lead to improvements in the ecological and societal values of the system.

III.2 Ecosystem Stressors

Stressors that have strong impacts on the Lake's natural and societal values are ***excessive phosphorus loading***, ***invasive plants***, and extreme high and low ***lake stage*** (**Figure 1**). High inputs of phosphorus to the lake from the surrounding watershed, along with high internal phosphorus loading are responsible for the Lake's accelerated eutrophication (Havens et al. 1996a, Moore et al. 1998). Concentration of phosphorus in the Lake's water column more than doubled in the last 30 years, from 40 to 50 ppb in the early 1970s to over 100 ppb in 2001 (SFWMD, 2002). The primary source of phosphorus pollution is agriculture, with lesser contributions from urban and other sources (Flaig and Havens 1995). As a result of decades of high inputs, the soils in the watershed, the sediments of tributaries, and the lake's bottom sediments now contain large quantities of phosphorus (Olila and Reddy 1993, Flaig and

Reddy 1995). These soils and sediments represent large secondary sources of phosphorus loading to the lake. The deep canals of the C&SF Project also facilitate delivery of phosphorus to the lake, bypassing wetlands that may have attenuated phosphorus concentrations under more natural conditions. Major goals of the LOPP include projects to control phosphorus sources in the watershed, capture phosphorus from tributary waters, and re-establish some of the historic wetlands.

In addition to high concentrations of phosphorus, the pelagic (open water) region of Lake Okeechobee experiences elevated concentrations of resuspended sediments, whose source is a region of soft organic mud that covers nearly 40% of the lake bottom (Fisher et al. 2001). When wind mixes the shallow water column, the upper few cm of mud are resuspended. This internal recycling far exceeds external loads, in terms of its gross contribution to nitrogen and phosphorus in the Lake's water column (James et al. 1997). The spatial extent, depth, and phosphorus content of this mud have increased rapidly in the last 100 years, coincident with agricultural development and increased nutrient inputs from the watershed (Brezonik and Engstrom 1999). One of the current projects under the LOPP is evaluating the feasibility of removing or chemically treating all or part of the phosphorus-rich mud, in order to potentially reduce internal phosphorus loading and improve water clarity.

Variations in rainfall, evapotranspiration, water supply deliveries from the Lake, and operation of the C&SF Project (including the regulation schedule, supply side management, and compliance with any Minimum Water Level criteria) have the potential to affect water levels (stage) in the Lake. This becomes stressful to the ecosystem when there is prolonged or extreme high or low lake stage. The impacts of high and low stage are more severe than they would have been when the dike did not encircle the lake. Under natural conditions, water was able to expand and recede over a large low-gradient marsh to the west and south. Today, when stage exceeds 15 ft, water simply stacks up over the much-reduced littoral zone, flooding it to a greater depth. When lake stage falls below 11 ft, the entire littoral zone is dry, and habitat is not available for wetland biota. Hence, extreme high or low lake levels of any duration, or moderate high or low lake levels of prolonged (>12 months) duration, can cause significant harm to the ecosystem, as described below in greater detail. In contrast to the harmful effects of extremes, a certain degree of natural variation in lake stage, between 12 and 15 ft, has been shown to be benefit the ecosystem (Smith et al. 1995; Smith 1997). This type of variation is a desired hydrologic result of water detention facilities constructed under the LOPP and CERP.

In recent decades, Lake Okeechobee has experienced a rapid expansion of exotic and nuisance plants, as well as introduction of some exotic animals. There now are 15 species of exotic plants in the lake's littoral zone. Species that have caused the most substantial harm are *Melaleuca* and torpedo grass, which were purposely introduced to the region, for dike stabilization and cattle forage, respectively. Other exotic plants that have stressed the lake's values include *Hydrilla* sp., water hyacinth (*Eichhornia* *crassipes*), and water lettuce (*Pistia stratiotes*). Exotic animals in the lake now include fish (*Tilapia aurea)*, mollusks (*Corbicula fluminea*), and microinvertebrates (*Daphnia lumholtzii*). Each of these species exerts different impacts on the ecosystem, as discussed below. Many of these species have been accidentally introduced to the lake, and this situation is likely to continue, as new species are introduced to the United States and subsequently spread by boats and other mechanisms into Florida waters.

III.3 Ecosystem Values

Two major values (**Figure 1**) reflect the overall health of the lake. The first ecosystem value is ***water quality***; defined in a generic sense, it deals with attributes of water chemistry that directly affect the quality of water for drinking, recreation, and other societal uses. It includes aspects of water quality related to taste, odor, visual appearance, dissolved oxygen, color, and potential toxins (e.g., trihalomethane precursors and blue-green toxins). The quality of water in Lake Okeechobee affects downstream ecosystems, including the St. Lucie and Caloosahatchee Estuaries, the Lake Worth Lagoon, and the Florida Everglades. The second resource value in the conceptual model is the Lake's ***fish and wildlife*** populations. Lake Okeechobee supports a commercial and recreational fishery that had an estimated economic value in excess of $300 million US dollars in the early 1990s (Furse and Fox 1994). The lake's fishery provides the resource base for a diverse community of birds and other animals. Both of these values should substantially improve as a result of projects constructed under the LOPP and CERP.

III.4 Ecosystem Effects

The pathways linking stressors to resource values are complex (**Figure 1**, boxes and arrows), but are well-understood as a result of scientific research and modeling carried out by scientists at the SFWMD, FWC, and the University of Florida (UF). As we learn more about how the ecosystem functions, it is possible that pathways could be added to the model, or adjustments made to existing pathways. Indeed there are a number of key uncertainties about this model that are described in Section VI of this Plan (Key Uncertainties and Research Questions). The conceptual model for Lake Okeechobee is a flexible planning tool that, at any given time, reflects the current state of scientific knowledge about the resource.

In the following sections of the Plan, the various ecosystem effects (**Figure 1**) are described here in numerical order, corresponding to the numbered arrows shown on the conceptual model diagram. Each arrow represents a <u>concept </u>(working hypothesis) based on existing scientific information. The working hypotheses are organized under the categories water quality, vegetation structure and function, and fish and wildlife.

III.4.1 Water Quality

Water quality in Lake Okeechobee has been dramatically affected by nutrients associated with human activities in its watershed. Total phosphorus concentrations measured in the lake today (>110 ppb) are more than double those measured in the early 1970s, when the SFWMD first began to collect water quality data on a regular basis (James et al. 1995a, SFWMD 2002). The high concentrations reflect a long history of excessive phosphorus inputs to the system (James et al. 1995b) and today, an internal load of phosphorus from the lake sediments approximately equals the external load (Moore et al. 1998). Turbidity of the lake water also is high, especially in the central pelagic region, due to resuspension of sediment material from the lake bottom (Maceina and Soballe 1991, Hanlon et al. 1998). During times when lake stage is high (>15 ft) there appears to be substantial transport of turbid, phosphorus-laden water from mid-lake to the south and west shoreline areas (Maceina 1993, Havens 1997), where another water quality problem occurs -- the development of dense blooms of noxious cyanobacteria (blue-green algae). When these algae occur in high densities they can cause taste, odor, and trihalomethane problems for the five municipalities that draw water from the lake for drinking. When the blooms peak and then collapse, aquatic animal life is threatened because of reduced dissolved oxygen concentrations and decay products from the algae (Jones 1987, Paerl 1988). At this time there is no definitive evidence of harmful levels of blue-green toxins in the water, however, species of blue-green algae known to produce toxins do occur in the Lake (Havens et al. 2002).

The following concepts describe the major factors considered to affect phosphorus dynamics in the lake, and correspond to pathways of effects in the conceptual model

Concept 1 – A high rate of phosphorus loading from the tributaries has resulted in high concentrations of phosphorus in both the water column and sediments of Lake Okeechobee.

The lake has experienced high rates of phosphorus loading from its watershed for many decades (SFWMD 2002). At present the loading is in excess of 500 metric tons/y, far greater than the amount considered appropriate by the USEPA (2000) or Florida Department of Environmental Protection (2000) to protect the ecosystem. When phosphorus enters the lake, a large fraction is stored in the lake sediments (James et al. 1995b). Due to the long history of high inputs, those sediments now contain over 30,000 metric tons of phosphorus in their upper 10-cm alone (Olila and Reddy 1993). Some of this phosphorus can be mobilized into the overlying water column by various processes, including diffusion (Moore et al. 1998), wind re-suspension (Hanlon 1999), and bioturbation (Van Rees et al. 1996). This internal loading makes the lake ecosystem very resilient to changes in its phosphorus concentration when external inputs vary, a situation that is common in shallow eutrophic lakes (Sas 1989, Moss et al. 1996). From a management standpoint, this means that lake responses to load reductions based on the implementation of projects in the LOPP are likely to occur with a long time lag. Eventually, however, phosphorus-rich surface sediments will be covered by new sediment material with reduced phosphorus content. When this occurs, rates of internal loading should begin to decline.

Concept 2 - Biological and chemical changes that have occurred in the lake due to cultural eutrophication have contributed to a "positive feedback" that helps maintain high phosphorus concentrations due to a lack of ecosystem assimilative capacity.

A phosphorus mass-balance for the lake indicates that every year, approximately 400 metric tons of that element is stored in sediments (James et al. 1995b). Hence the lake is described as a "net sink" for phosphorus. However, since the early 1970s, this internal storage of phosphorus has been declining (Havens and James 1997), suggesting that the lake's assimilative capacity is being used up. That might occur for example, if the binding sites (calcium and iron minerals) on sediment particles became saturated with phosphorus. There is some evidence that this is occurring. Fisher et al. (2001) compared the concentrations of sediment pore-water phosphorus in samples collected from the lake in 1988 vs. 1998, and found that they had more than doubled. Pore-water phosphorus is unbound phosphorus that essentially is a surplus or non-assimilated fraction. At this point we assume that this increase in pore-water phosphorus reflects a reduction in binding sites, and hence a reduction in assimilative capacity. If external phosphorus loading rates remain high, a further loss of sediment assimilative capacity might occur. On the other hand, this trend should reverse after a period of substantially reduced external phosphorus loads (Havens and Walker 2002).

Along with these chemical processes, there have been a number of biological changes in the lake that could reduce the system's capacity to assimilate phosphorus (Havens and Schelske 2000). In the lake's water column, diatoms have been replaced by cyanobacteria as the dominant phytoplankton (Cichra et al. 1995), and this could decrease the rate of phosphorus transport to sediments because cyanobacteria settle more slowly than diatoms in the lake's water column (Reynolds 1984). Among the benthic macro-invertebrates, oligochaetes have replaced chironomids and other insect larvae as the dominant taxa (Warren et al. 1995), largely because they are able to tolerate the anoxic conditions that occur in the lake's enriched sediments (Warren et al. 1995). This macro-invertebrate trend may have resulted in a reduced net loss of phosphorus from the lake water because oligochaetes can pump soluble phosphorus from the sediments into the overlying water when they feed (Van Rees et al. 1996). Likewise, the lake's fish community contains a relatively large proportion of taxa that feed in the benthos, providing another pathway for upward phosphorus transport. There is a potential for reversal of these biological changes if phosphorus loads to the lake are reduced.

Concepts 3,4 - Blooms of noxious cyanobacteria and their associated adverse impacts on water quality are a direct consequence of high phosphorus concentrations.

The relationship between cyanobacteria blooms and phosphorus enrichment has been well established in the literature (Horne 1979, Paerl 1988). In lakes with prolonged high rates of external loading, phosphorus often reaches concentrations where it is in surplus relative to algal demands. When this occurs, some other nutrient element (most often nitrogen) becomes limiting (Schelske 1984) to algal growth. Havens (1994) documented a trend in lake water quality indicative of a transition towards secondary nitrogen limitation after the early 1980s, and Aldridge et al. (1995) and Phlips et al. (1997) documented that nitrogen now is the primary limiting nutrient for phytoplankton growth in the lake. In contrast, Brezonik et al. (1979) documented that there once was considerable phosphorus limitation. Nitrogen limitation favors dominance by bloom-forming cyanobacteria that can (1) remain buoyant in the water column, and (2) obtain nitrogen from the atmosphere by the process of nitrogen fixation (Horne 1977). Taxa that have this capacity include *Anabaena, Aphanizomenon, Cylindrospermopsis,* and *Microcystis*. Most often, *Anabaena* predominates in Lake Okeechobee when it experiences dense algal blooms on the water surface. Present conditions of low nitrogen: phosphorus ratios strongly favor these algae, although high solids concentrations caused by sediment resuspension may often suppress their growth (Havens et al. 2002a). Nitrogen-fixing blue-green algae can impact water quality by producing toxins and by causing taste and odor problems. Since they are not heavily grazed by zooplankton (see below), they can contribute significantly to the production of dissolved organic carbon compounds in the water column that are precursors for the formation of carcinogens known as trihalomethanes (Paerl 1988, Cooke and Carlson 1989).

When noxious blue-green algae dominate, there also are dramatic changes in the structure and function of the lake's food web, which could translate into a poorer quality food resource for fish and other animals. Noxious cyanobacteria are not readily grazed by zooplankton (micro-invertebrates in the open water region). Therefore, much of the carbon that is taken up by the algae during photosynthesis is either tied up as unused production until the cells die, or is released into the water as excreted dissolved organic carbon (DOC). This DOC can fuel growth of bacteria, whose production tends to be greatly elevated in highly eutrophic, blue-green dominated lakes (Porter et al. 1988, Kamjunke et al. 1997). Pathways for transferring bacterial production to zooplankton, and subsequently to fish, have low efficiency because the food chains have many steps or links (Stockner and Shortreed 1989), and hence, much of the energy taken into the system during photosynthesis is lost in respiration.

If projects carried out under the LOPP result in reduced in-lake phosphorus concentrations, levels of surplus phosphorus may be reduced to the extent that phosphorus again becomes the nutrient most often limiting to phytoplankton growth. That condition would favor dominance of diatoms and other algae over cyanobacteria, resulting in a reduction in the frequency of algal blooms. If LOPP projects substantially reduce phosphorus concentrations, but nitrogen levels similarly decline (hence, no change in the nitrogen: phosphorus ratio), nitrogen fixing blue-greens might continue to dominate, but at a reduced biomass. The actual response (continued blue-green dominance or not) could have strong implications for ecosystem function, given the above discussion regarding algal vs. bacterial production. Given the strong dependence of toxin-producing blue-greens (e.g., *Cylindrospermopsis*) on nutrient ratios and underwater light availability, further research is needed to predict how this aspect of lake water quality is likely to respond to proposed LOPP projects. It may be prudent to consider how particular projects will affect nitrogen loads, in addition to a primary focus on phosphorus. In-lake projects (e.g., sediment removal or treatment) that could reduce phosphorus recycling, but also modify the underwater light climate, also need to be carefully evaluated in the context of response of potentially toxic blue-greens.

Concept 5 – Algal blooms and their decay products have impacted the lake's benthic macro-invertebrate and zooplankton communities, which are the food base for fish and other wildlife.

As a result of sustained high rates of nutrient loading and high rates of phytoplankton production, there has been a high rate of organic loading to the lake sediments, high rates of bacterial metabolism, and hypoxic or anoxic conditions in the near-surface sediments. These conditions collectively favor the dominance of "pollution tolerant" macro-invertebrates such as certain oligochaetes. Warren et al. (1995) documented that between the early 1970s and early 1990s, the relative abundance of oligochaetes increased in the pelagic sediments from 30 to 80% of the total community. This high relative abundance persisted during the last decade (Warren, personal communication), and species known to be pollution-tolerant (e.g., *Limnodrilus hoffmeisteri*) continued to be abundant. At the same time, species that previously occurred in the lake and still occur in nearby unpolluted lakes (various ephemeropterans and trichopterans), have become rare or absent in Lake Okeechobee. These trends are nearly identical to those observed in Lake Erie when it underwent rapid eutrophication between 1930 and 1960 (Carr and Hiltunen 1965).

The predominance of oligochaetes is a concern for two reasons. First, as mentioned above, they can contribute substantially to the internal loading of phosphorus. Second, they do not have an adult stage that emerges from the water (as occurs for ephemeropterans, trichopterans, and other aquatic insects), and therefore do not provide a food resource for animals that feed on such emergent forms. This includes migratory waterfowl and a variety of fish. If projects implemented under the LOPP result in a substantial reduction in phosphorus loading to the lake, at some time in the future the surface lake sediments may be less enriched with nutrients and organic matter. If this occurs the sediments will be a more favorable habitat for a diverse benthic macro-invertebrate community, and the dominance of oligochaetes should decline. The timing and extent of this recovery are uncertain.

Nutrients also have affected the Lake's zooplankton, which is comprised of 61 native and one exotic species (Havens et al. 1996b). Total biomass of zooplankton in this lake is a function of resource (edible algae) availability (Crisman et al. 1995, Havens et al. 1996c) but the taxonomic composition appears to be controlled by fish grazing (Beaver and Havens 1996). As in other Florida lakes (Crisman and Beaver 1990), only small species and those with escape tactics dominate. These species are not effective grazers of large algae. When coupled with the dominance by large blue-greens, this translates into very low food web efficiency. Havens and East (1997) and Havens et al. (2000) documented that less than 1% of photosynthetic carbon is transferred upward to zooplankton in this lake.

If projects implemented in CERP and the LOPP result in reduced nutrient inputs to the lake and declines in inedible phytoplankton and bacterial production, the total biomass of zooplankton might be expected to decline. Yet this decline might be ameliorated by improvements in food quality (a shift from inedible cyanobacteria to edible diatoms), leading to a more efficient food web. It is uncertain how CERP and LOPP projects will affect the taxonomic structure of zooplankton, which is likely to continue to be determined by predation.

Concepts 6 - 9 - High lake stage exacerbates phosphorus impacts, by facilitating transport of phosphorus and sediments to shoreline areas, where it stimulates algal blooms and reduces light availability for submerged plant growth.

There is a strong link between stage and total phosphorus (Canfield and Hoyer 1988, Havens 1997); however, the underlying mechanisms may be complex, ranging from large-scale changes in the physics of water circulation to alterations in the interaction between biological communities. One of the first effects to be suggested (Maceina 1993) was that at high stage there is greater horizontal transport of phosphorus from the mid-lake region, where concentrations are highest due to the re-suspension of underlying mud sediment, into more phosphorus-deficient near-shore areas. The evidence for this hypothesis was largely observational, but it has been supported with results from the SFWMD Lake Okeechobee Hydrodynamic Model (Jin et al. 2000). The underlying mechanism is related to underwater currents and the morphology of the lake basin. When wind moves across the lake surface it creates large circulation gyres whose spatial extent is affected by water depth. When lake stage is low (<13 ft), an elevated ridge of limestone along the south and west perimeter of the lake hinders mixing of water between the mid-lake and shoreline regions. This is thought to reduce phosphorus and sediment transport to the shoreline region and be responsible, in part, for the low phosphorus concentrations and high transparency that occur there when stage is low (Havens 1997). A recent analysis of comprehensive data collected in the Lake's south and west shoreline areas confirmed this hypothesis, by documenting a strong synchronized rise and fall of lake stage, suspended solids, and phytoplankton chlorophyll *a* at >40 sampling stations over a 3-year period (Havens 2002).

Another factor that may become important at low lake stage is uptake of phosphorus by submerged aquatic vegetation (SAV), as suggested by Phlips et al. (1993). During years when stage is low, the lake can support a large spatial extent of SAV (Hopson and Zimba 1993). For example, in 1989, after stage declined to below 11 ft, remote sensing indicated that submerged plants covered 12,400 ha of the lake bottom (Richardson and Harris 1995). In summer 2000, after a managed lake recession operation and a decline in stage to below 12 ft, the total extent of submerged plants determined from an intensive field survey was 17,700 ha. Havens (2002) documented that at locations in the lake colonized by a high density of SAV, there are significantly lower concentrations of total solids and phytoplankton chlorophyll *a*, and significantly higher water transparency. The SAV has the capability to reduce water column solids, phosphorus, and chlorophyll concentrations by a number of processes. These include: (1) stabilization of lake sediments by plant roots; (2) reduction of water flow velocity and shearing stress on sediments due to wave attenuation (Vermaat et al. 2000); (3) trapping of sediment material; (4) direct uptake of phosphorus by roots in the sediments or from the water by epiphytic algae (Carnigan and Kalff 1982, Burkholder et al. 1990). In Florida lakes up to 96% of the combined water column and macrophyte phosphorus can occur in the tissues of macrophytes (Canfield et al. 1983).

Benthic micro-algae and *Chara*, a macro-alga, also can become abundant under low stage conditions in Lake Okeechobee (Steinman et al. 1997a,b), and these algae can directly compete for water column phosphorus with phytoplankton (Havens et al. 2001, Hwang et al. 1998). When lake stage is high, the growth of macrophytes and attached algae is suppressed due to light limitation caused by the deeper water and the high turbidity that accompanies greater materials transport from the mid-lake region. Hence lake stage can affect water column phosphorus concentrations by determining the relative mass of that nutrient that occurs in attached macrophytes and algae (high when lake stage is low) or phytoplankton (high when lake stage is high).

When alternative water storage locations (ASR wells, regional storage reservoirs, RaSTAs, isolated wetlands) are brought on line under the LOPP and CERP, it is predicted that there will be a reduced number of high lake stage events in Lake Okeechobee. This should indirectly benefit water quality in the lake, by providing conditions where there is both reduced horizontal transport of phosphorus into the shoreline area and increased growth of macrophytes and attached algae that can remove phosphorus from the water. Certain water storage projects (including ASR) are expected to have direct effects on water quality, reducing inputs of nutrients to the lake and/or increasing inputs of mineral elements, such as calcium, that can help to tie up biologically available phosphorus in the system.

III.4.2 Vegetation Structure and Function

In the early 1970s, the littoral zone supported a diverse array of native plants (Pesnell and Brown 1973). The community included large areas of spikerush, sawgrass (*Cladium jamaicensis*), willow (*Salix caroliniana*) and beakrush (*Rhynchospora tracyi*). At the south end of the lake there were remnant stands of pond apple (*Annona glabra*) and along the western shore there was a nearly continuous band of dense bulrush immediately lake-ward of a zone dominated by spike rush and submerged plants. Although there is no quantitative record, various anecdotal reports from the early 1970s indicate that the submerged plant beds were both widespread and dense, including species such as eelgrass and peppergrass, which are favorable habitats for fish (Furse and Fox 1993).

Today the vegetation mosaic of the littoral zone is dramatically different (Richardson and Harris 1995). Upland areas that previously were dominated by beakrush and mixed grass assemblages have been infested by the invasive exotic torpedograss. Certain areas have become dominated by the exotic tree melaleuca (*Melaleuca quinquenervia*), although much of that species has been killed by herbicide (SFWMD 2002). The spatial extent of willow has declined and there has been a large expansion of cattail, both along the western shoreline and in the interior littoral zone, where boat trails allow movement of nutrient rich water into that area when stage is high. The shoreline bulrush stands are reduced relative to their historic amounts, although a period of low stage in 2000-2001 allowed considerable bulrush recovery to occur. It also allowed for recovery of a shoreline community of spikerush that had not been documented since the 1970s (Pesnell and Brown 1977). In the late 1990s, submerged vegetation was virtually eliminated from the near-shore region of the lake due to high water, but a strong recovery occurred from 2000 to 2002, during a drought and a period of low water level. In 1999, the lake was estimated to support just 3,000 acres of submerged vegetation, but in summer 2002, a comprehensive survey indicated over 43,000 acres of plants. It is uncertain how long these recent improvements in vegetation structure will last, however, because until major projects are constructed under CERP, the Lake will continue to be the main location for water accumulation during periods of heavy rainfall in the tributary basins. Thus, periods of damaging high water may again occur, leading to degradation of vegetation quality.

Concepts 9,10 - In the littoral and near-shore zones, the distribution of native and exotic plants primarily is determined by water depth and/or hydroperiod.

Short hydroperiod regions of the Lake's littoral zone support native species including spikerush, beakrush, willow, and cordgrass (*Spartina bakeri*), and exotic species including torpedograss, melaleuca, and brazillian pepper (*Schinus terebinthifolius*). Long hydroperiod regions support spikerush, cattail, sawgrass, bladderwort, and water lily. Periods of extremely short or long hydroperiod that have occurred since the early 1970s are considered to be responsible for changes in the relative distribution of these plants (Richardson and Harris 1995).

Three periods of very low lake stage, in 1980-81, 1989-90, and 2000-01, may be responsible for considerable expansion of exotic plants in the littoral zone. Controlled experiments with *Melaleuca* (Lockhart 1995) and torpedograss (Smith et al. 2002) indicate that these species cannot successfully invade native plant habitat that is inundated with water. *Melaleuca* seeds cannot effectively germinate under water, and fragments of torpedograss (this plants main mode of colonization) cannot establish roots when water depths exceed 50 cm. However, once these plants are established, they can tolerate relatively deep and prolonged flooding.

When lake stage is low there also is an increased probability of fire occurring in the littoral zone, either due to natural causes (e.g., lightening strikes) or in controlled burn programs. Fires have documented benefits to the littoral vegetation mosaic. Fires burn away accumulated thatch in dense stands of emergent macrophytes, opening up the habitat to wildlife, and they also burn away much of the above-ground biomass of torpedograss monocultures, which allows for more effective control of this exotic with herbicide (Hanlon and Langeland 2000). Fires also allow buried seeds to germinate from the exposed sediments, providing the potential for species to re-colonize the habitat (Williges and Harris 1995).

Several years of high lake stage in the late 1990s are considered responsible for changes that have occurred in the dominance of native plant species in the interior littoral zone. From 1994 to 2000, lake stage exceeded 17 ft on four occasions and never fell substantially below 13 ft. These conditions may have favored development of dense stands of water lily in a west-central littoral region called "Moonshine Bay" where there previously was only spike rush and bladderwort. The dense lily communities may have degraded this habitat for fish and wildlife use due to a thick accumulation of dead leaf material and coarse organic detritus, which occupies up to 80% of the water column depth at some sites (SFWMD staff, personal observation).

High lake stages also may be the reason for a loss of large continuous stands of woody vegetation, in particular willow (*Salix caroliniana*) and pond apple (*Annona glabra*) that historically may have provided nesting sites for large colonies of wading birds in the Lake's littoral zone. The lake stage regime expected under CERP and the LOPP more closely mimics that which occurred in the early 1970s, when there was more widespread occurrence of desirable littoral plants, including spikerush, beak rush, and willow. Therefore the restoration programs should favor that type of littoral vegetation mosaic. The post-restoration stage regime is expected to include some periods of low lake stage (albeit at a reduced frequency, intensity, and duration), which will have both positive and negative effects. Positive effects include drying and oxidation of accumulated organic debris. Negative effects include increased spread of exotics, invasion of exposed lake bottom areas by terrestrial plants that subsequently die and release nutrients, and invasion by weedy plants that can tolerate flooding – such as *Polygonum*. An aggressive program to control the spread of torpedograss is under development, and along with the ongoing *Melaleuca* eradication program, is considered a critical long-term measure to complement the modified hydro-pattern. One of the ancillary benefits of lower water levels is likely to be expansion of the Okeechobee gourd (*Cucurbita okeechobeensis*), a Federally endangered plant that occurs on islands at the south end of the lake (SFWMD 2002). Its abundance has been negatively affected by flooding during years of high lake stage.

Prolonged periods of deep water, combined with damage from wind-driven waves, have also dramatically reduced the spatial extent and biomass of near-shore bulrush stands and submerged aquatic vegetation. Recent estimates indicate that the spatial extent of bulrush has been reduced by 50% from its recorded maximum in the early 1970s (Florida DEP, unpublished data). Two factors may interactively have contributed to this decline. First, long periods of deep standing water may have resulted in conditions where only a small percentage of the plant's photosynthetic tissues were above water (Hanlon 2000). Under those circumstances, bulrush has been documented to draw on its underground rhizomes as an energy reserve, until eventually the plants have insufficient energy for net growth and survival (van der Valk 1994).

In a similar manner, high water had resulted in a dramatic decline in the spatial extent of submerged aquatic vegetation by 1999, following several years of high lake stage. High water levels have two related effects on underwater irradiance, and in turn, on the rate of growth and survival of submerged plants. First, when lake stage is high, light reaches the bottom only in a limited area close to the lake shore, where depths are shallow. This limits the lake-ward extent of submerged plant habitat. Second, under high stage conditions, there is increased transport of sediment-laden water from the mid-lake area (where these sediments are resuspended by wind) to the near-shore area that supports submerged plants (Maceina 1993, Havens 1997). When combined with a deeper water column, the increased turbidity results in little or no light reaching the lake bottom. Research has shown that submerged plant biomass in Lake Okeechobee is negatively correlated with water depth (Hopson and Zimba 1993) and that the highest submerged plant biomass occurs when stage is very low (Phlips et al. 1993).

Once submerged plants are lost, a positive feedback maintains the turbid condition. Without plants to stabilize sediments, there is increased sediment resuspension and no competition with phytoplankton for nutrients. Resuspended sediments and algal blooms result in higher turbidity, which prevents plant recovery. This cycle is very difficult to break once it is established (Scheffer 1989). Only dramatic actions, such as a considerable lowering of stage, allow plants to re-colonize the site. Once this occurs, however, the plants can establish a different feedback loop that maintains clear water (the plants support sediments and they also remove nutrients from the water so that algal blooms do not occur). The LOPP and CERP are expected to result in a lowering of average water levels in the lake and a reduced frequency of extreme high water levels (when damaging wave effects occur). Under those conditions, the distribution and abundance of bulrush and submerged plants are expected to increase.

High water levels in the Lake also have eroded the western shoreline, and produced a dense organic "berm" of dead plant material and lake sediment at the pelagic-littoral interface. According to biologists who have worked on the lake since the 1960s, these organic berms are a common feature of the impounded system. The recent berm, however, is considered to be the most large-scale and permanent one ever to have occurred. In some areas the berm is over 1 m tall, greater than 10 m wide, and it has established a community of woody vegetation including small willow trees. Scientists at the FWC have expressed concern that this organic berm is ecologically harmful because: (1) it may prevent normal water exchange between the littoral zone and marsh, in particular, it may block the egress of water from the marsh after periods of heavy rainfall over that area; (2) it may block normal migration routes for fish; and (3) it may act as a "break-wall" that does not gradually attenuate waves in the manner that an edge of vegetation would, and this causes erosion of sediments and any submerged plants that might develop at its lake-ward edge. Recently the FWC, SFWMD, and USACE carried out a project that removed several linear miles of berm, and efforts are under way (with funding from the Florida Legislature) to remove additional berm material. Under a lower lake stage schedule with CERP and the LOPP completed, it is predicted that littoral shoreline erosion and berm formation should be substantially reduced.

Concepts 12,13 - Excessive inputs of phosphorus from the lake's pelagic zone have promoted the spread of cattail in certain littoral areas and may have contributed to expansion of water lily. In areas of dense cattail and thick accumulations of detritus from lily and other invasive plants, poor light conditions and low dissolved oxygen concentrations occur.

The pelagic zone of Lake Okeechobee has total phosphorus concentrations that average over 100 ppb (James et al. 1995a), while concentrations in the interior littoral zone are typically between 10 and 15 ppb (Havens et al. 1997, Hwang et al. 1998). At high lake stage, currents transport phosphorus-rich water from mid-lake towards the pelagic-littoral interface (Maceina 1993, Havens 1997) and into the littoral zone proper. This phenomenon recently has been documented by the District's lake hydrodynamic model and by evaluation of water quality data during recent years when lake stage has been high. Studies of periphyton communities in the littoral zone indicate that there have been nutrient impacts similar to those observed in the Everglades (McCormick et al. 1996).

Aerial photographs and early maps (Pesnell and Brown 1973) of the littoral zone indicate that in the 1970s there was little or no cattail in the area of Moonshine Bay. In general, the area was characterized by a near-monocluture of spikerush. Today there is dense cattail along the edges of all boat trails leading from open water into Moonshine Bay from the north and west. There also is a dense "wall" of cattail along nearly the entire western shoreline, where the plant community is in direct contact with pelagic water (Richardson and Harris 1995). Recently, cattail has displayed further expansion in South Bay, near King's Bar, and in Fisheating Bay, near areas where nutrient-rich water enters the ecosystem from tributaries. Stimulation of cattail growth by phosphorus enrichment and high water levels in Lake Okeechobee is consistent with results from experimental research carried out in the Everglades (Newman et al. 1996).

Areas of dense cattail, torpedograss, and other invasive plants provide poor habitat for fish and other wildlife. The plants shade the underlying water, so that there is not sufficient light for growth of periphyton (Grimshaw et al. 1997), and with low rates of photosynthesis by algae, coupled with high rates of bacterial mineralization of dead organic material, dissolved oxygen concentrations become very low.

Under CERP and the LOPP, it is anticipated that the duration and return frequency of high water events will be reduced, and phosphorus inputs to the lake also should decline as a result of LOPP / CERP projects. Taken together these actions are expected to result in less phosphorus transport into the littoral zone, and a reduced rate of cattail expansion.

III.4.3 Fish and Wildlife

Lake Okeechobee supports a nationally recognized sport fishery for largemouth bass (*Micropterus salmoides*) and black crappie (*Pomoxis nigromacultus*), as well as a commercial fishery for various catfish and bream (*Lepomis* spp.). According to Fox et al. (1993) these fisheries generated nearly $30 million per year for the local economies in the early 1990s, and they had an asset value that was in excess of $100 million (Bell 1987). Another estimate (Furse and Fox 1994) placed the value of the fishery in the early 1990s at more than $300 million, and considered only the recreational fish species.

In total, the Lake supports 41 species of fish (Bull et al. 1995, Havens et al. 1996b) that provide a food resource for wading birds, alligators, and other animals. Fish use both the littoral and pelagic regions of the lake and some of the top predators (including largemouth bass and Florida gar, *Lepisosteus platyrhincus*) display a migration between the two habitats (Fry et al. 1999). The fish use a wide range of food, including macro-invertebrates and zooplankton (Havens et al. 1996b, Fry et al. 1999). These in turn are dependent on a continual input of energy in the form of plant, periphyton and phytoplankton primary productivity, and allochthonous inputs of carbon that can fuel bacterial growth. Fish also depend on the lake's aquatic plant communities to provide them with spawning habitat, to serve as a refuge from the environment and predators, and to support the complex food web described above (Fox et al. 1993).

As a result of human impacts on the lake, there have been dramatic changes in both the resource base that supports the fishery and the aquatic plant communities that provide fish habitat. These changes include eutrophication-related shifts in macro-invertebrate and plant community structure, and large-scale loss of certain plant community components due to stresses associated with high water. In fall 1999, scientists at the Florida Fish and Wildlife Conservation Commission (FWC) reported declines both in the population size and early age classes of important sport fish, a result that likely is related to some of the ecosystem changes that recently have occurred. Other components of the lake's wildlife community (e.g., wading birds and migratory water fowl) also may have been affected by eutrophication and high-water related changes in the food web and habitat structure.

Concepts 15, 16 – Macro-invertebrates and forage fish in the littoral and near-shore regions of the Lake are strongly dependent on the habitat values provided by submersed and emergent macrophytes.

Under favorable conditions, near-shore macrophyte habitat, including *Hydrilla verticillata, Potamogeton illinoinsis* (peppergrass), *Scirpus* sp. (bulrush) and *Vallisneria americana* (eelgrass) support a high biomass of macroinvertebrates (Warren and Vogel 1991). Many of these macro-invertebrates, including the grass shrimp *Palaemonetes paludosus*, the amphipod *Hyalella azteca*, and larvae of the midge genera *Dicrotendipes, Glyptotendipes*, and Rheotanytarsus, are integral to the diets of largemouth bass, black crappie, redear sunfish (*Lepomis microlophus)*, and bluegill sunfish (*L. macrochirus*).

With the recent (1990s) declines in near-shore macrophytes, much of the habitat for invertebrates important in the diets of sport fish has been eliminated. In a June 2000 survey, Warren and Hohlt (FWC, unpublished data) recorded extremely low densities of invertebrates in habitats (bulrush and mud sediments) that formerly (1987-1991) supported high numbers. Scientists and members of the public who frequent the lake also noticed a near absence of winged adult midges emerging from the lake during summer 2000. As noted above, these kinds of changes have potential negative consequences for birds and fish that depend on immature and adult invertebrates as a food resource. The extent to which these communities recover as a result of low water levels (<12 ft) and increased macrophyte biomass in 2000 remains to be seen.

If projects implemented in CERP result in a reduced frequency of prolonged and/or extreme high lake stage events, the near-shore bulrush community is likely to recover some of its previously greater spatial extent and density. When this occurs there should be a concomitant increase in the abundance of macroinvertebrates dependent upon submersed and emergent macrophyte habitats.

Warren and Hohlt (1994) examined littoral macroinvertebrate community sturcture on *Eleocharis* sp. (spikerush), *Panicum repens* (torpedograss), *Pontaderia sp.,* bulrush, and *Typha* sp. (cattail). Because of their growth habits, the torpedograss, *Pontaderia* and cattail habitats were characterized by low dissolved oxygen concentrations and poor quality macroinvertebrate communities. Spikerush habitat had a more vertical growth form and lower production of thatch material, and was characterized by higher dissolved oxygen concentrations and a higher quality macroinvertebrate community.

Based on surveys conducted by the FWC, we also know that the littoral zone includes at least 174 macro-invertebrate taxa (Havens et al. 1996b), representing a wide range of functional and taxonomic groups. Analysis of fish gut contents and stable isotope studies reveal that macro-invertebrates represent important diet components for small forage fish and sport fish in the interior littoral zone (Havens et al., manuscript in prep.). Macro-invertebrates were found to account for >40% of the volumetric gut contents of redear sunfish, bluegill sunfish, largemouth bass, and bowfin (*Amia calva*) at a sampling site in Moonshine Bay, located in the west-central littoral zone.

One of the most visible members of littoral macro-invertebrate community, from a resource management perspective, is the Florida apple snail (*Pomacea paludosa*). This species is a principal food item for the federally endangered Everglades snail kite (*Rostramus sociabilis)* (Bennetts and Kitchens 1997), and it also is consumed by certain wading birds, migratory water fowl, turtles, and small alligators. As such, it is an important component of the littoral food web. Research dealing with apple snails in south Florida (Turner 1996, Darby et al. 1997) indicates that: (1) the most favorable habitat for these animals includes a mosaic of sparsely and densely vegetated habitats; (2) animals survive only for 12 to 18 months, and lay their eggs on emergent vegetation during a 4 to 12 week period between March and July; and (3) juvenile snails can survive drying for 2 to 3 months. Dry-downs are not necessarily harmful to the snail populations, as long as they do not coincide with the peak period of egg production or last for many months, so that a large percentage of the existing population is killed. Since snails are slow-moving animals, re-population of large areas following prolonged dry downs may require multiple years of favorable conditions.

Another factor that can significantly impact apple snails is reversal of lake stage during the egg laying period. Snails lay their eggs several cm above the water surface on the emergent stems of spike rush, bulrush, cattail and other plants (Darby et al. 1997). If lake stage rises during this period and eggs become flooded, they experience high mortality due to physiological effects on developing snail embryos and from loss of adhesion to stems (Turner 1994).

Research dealing with apple snail growth responses to varying food types indicates that the nutrient content of grazed material also could affect the populations. Sharfstein and Steinman (2001) maintained young apple snails in laboratory cultures, and provided the animals with either the epiphyton associated with spike rush stems, epiphyton of bladderwort, or metaphyton collected from near the sediment surface. These are three distinct and typical components of the periphyton community in the lake's central littoral zone (Havens et al. 1997). Snails feeding on bladderwort epiphyton grew significantly more than snails feeding on the other food types, perhaps because the bladderwort epiphyton had a higher nitrogen and chlorophyll content. Changes in plant community structure that shift the periphyton towards a dominance by less nutritious forms could potentially result in reduced apple snail growth. The extent to which human factors might be expected to bring about such a change is unclear.

Three major predictions emerge from what is presently known about the littoral macroinvertebrate community. First, it is predicted that apple snails and other beneficial invertebrates will benefit from lake stage operations that minimize the frequency of prolonged spring draw-downs that dry out their habitat (i.e., prolonged lake stages below 12 ft). Second, it is predicted that snails and other invertebrates will benefit from operations that minimize the occurrence of stage reversals during the March-July period of maximal egg laying. Third, it is predicted that snails and other invertebrates will benefit from lake stage operations and other management actions (e.g., exotics control) that maintain a diverse mosaic of native littoral vegetation types, including spike rush, bladderwort, bulrush, sawgrass, and other emergent species.

Concept 17 -- The abundance and taxonomic composition of fish in the lake's pelagic zone is affected by nutrient inputs to the system, which determine the biomass of phytoplankton in the water column and macro-invertebrates in the benthos.

Bull et al. (1995) studied the distribution of fish in open-water habitats of the lake during the late 1980s and early 1990s, sampling fish at 25 sites with a large trawl net. They found that the deeper central and north regions of the lake supported distinct fish assemblages, which differed from those found in the near-shore and littoral habitats. The central assemblage was dominated by threadfin shad (*Dorosoma petenense*) and black crappie (*Pomoxis nigromaculatus*) in summer, and by black crappie and white catfish (*Ameirus catus*) in winter. The abundance of shad was significantly correlated with phytoplankton chlorophyll *a* concentrations. This reflects a feeding preference for phytoplankton and zooplankton (Baker and Schmitz 1971). White catfish abundance was strongly correlated with water depth, indicating the fact that these species tend to forage in the cooler deep water areas of the lake, where they prey on benthic macro-invertebrates, detritus, and smaller fish (Havens et al., manuscript in prep). Bull et al. (1995) documented that the north pelagic region is strongly dominated by threadfin shad and black crappie. It supports the highest densities of these species both in summer and winter, probably due to high food availability. Phlips et al. (1995) documented that the north region, in closest proximity to high nutrient inputs from agricultural tributaries, displays high phytoplankton biomass. The phytoplankton provides a direct source of food for shad, and also a source of organic matter loading to support a high biomass of benthic macro-invertebrates. Black crappie prey heavily on *Chironomus crassicaudatus*, a chironomid that occurs at extremely high densities (up to 21,000 per m^2) in the nutrient-rich mud sediments that occur in the northern region (Warren et al. 1995).

Substantial reductions in nutrient loading to the lake, brought about by projects in the LOPP, might lead to declines in the abundance of certain fish taxa (e.g., threadfin shad, black crappie). These fish presently occur at high densities due to an abundance of food resources (phytoplankton and certain chironomids) linked to high rates of nutrient inputs. On the other hand, other changes in the lake that benefit certain fish might counteract these declines. Crappie recruitment has been low in recent years (Michael Allen, University of Florida, personal communication) and this has been linked to high lake stage. Hence a rehabilitated lake, with lower stages and reduced nutrient loads, might actually support a healthier population of that sport fish than is the case for the existing lake system.

Concepts 14, 18 -- Fish that spend all or part of their life cycle in the littoral zone of Lake Okeechobee are affected by factors that significantly alter the structure of the habitat, its resource base, and its water quality.

In general, a lake's vegetated littoral zone provides important habitat for fish, in particular for small forage fish taxa and the juvenile stages of larger species, which use the littoral zone as a refuge from predators and as a foraging area (Werner et al. 1983, Rozas and Odum 1988). In the case of Lake Okeechobee, surveys by Chick and McIvor (1994) documented a high biomass and diversity of fish in the littoral zone, with distinct fish assemblages occurring in different plant communities (eelgrass, peppergrass, and hydrilla). This is similar to the findings of Furse and Fox (1993) except that in this case, the focal point of the study was the interior and northern littoral regions, rather than the near-shore area. Fry et al. (1999) also documented, using stable isotope data, that a variety of fish may begin life in the lake's littoral zone and then migrate out into deeper water as they grow in size and "move up" in the food chain.

Chick and McIvor (1994) concluded that the littoral zone should be viewed as a complex landscape, comprised of distinct habitats that provide varying resource, refuge, and other features for the fisheries. This finding is important, but it seriously complicates our ability to understand the full suite of factors affecting fish while they are in the littoral zone. The landscape contains more than 30 distinct vegetation types, including emergent, submerged, and floating-leaf plants with dramatically different densities and growth forms. One thing that seems clear, however, is that certain rapidly expanding exotic and nuisance plants create conditions that generally are not favorable for fish. Species of particular concern are torpedograss and cattail. Greater detail regarding the expansion of these plants and conditions favoring their dominance is provided below under "native vegetation mosaic." In brief, both species have spread over tens of thousands of acres in the lake's littoral zone, displacing native plant communities that provide good habitat for fish and wildlife.

One of the displaced plants, spikerush, provides particularly good habitat for fish (Chick and McIvor 1994). It includes enough open water to allow large fish to effectively forage, but also provides cover associated with the emergent plant stems and associated whorls of bladderwort (*Utricularia* spp.) that are common in this habitat. The spikerush community also supports a high diversity of macro-invertebrates and attached periphyton that provide a food resource for the fish. In contrast, both torpedograss and cattail display a very dense growth form, with little open water for animals to move through and, as a result of the poor light conditions, little or no periphyton. Water quality inside dense stands of torpedograss also is not suitable for aquatic animals. Nighttime dissolved oxygen concentrations typically are near zero and mid-day values are as low as 0.5 mg/L (SFWMD, unpublished data).

The spread of torpedograss, as discussed below, may largely be a function of the occurrence of low lake stage, since expansion is favored when there is little or no standing water over the sediment surface. Expansion of cattail may be a function of phosphorus inputs from the pelagic zone and periods of long hydroperiod (Newman et al. 1996). The conditions that promote cattail expansion also may be responsible for the increased density of water lily (*Nymphaea* spp.) that has been observed in the interior littoral zone in the last several years. In areas where the density of this plant is high, there has been a deep accumulation of dead leaf material and coarse organic detritus, sometimes leaving only 5 to 10 cm of open water column. This habitat is not considered to be suitable for fish foraging or reproduction (FWC staff, personal communications). Recent years of long hydro-period also have allowed a deep accumulation of periphyton and detritus in spikerush areas, such that sandy substrate (good fish nesting habitat) is less available.

If projects implemented in the LOPP and CERP result in a reduced occurrence of prolonged high or low stage, the conditions that have favored expansion of cattail, water lily, and torpedograss should be reduced in their occurrence. This situation, along with active measures (controlled fires and/or herbicide application) to kill torpedograss and cattail, should provide benefits to the lake's fish and wading bird communities.

Concept 19, 20 -- Fish in the near-shore region depend heavily on the occurrence of a healthy community of submersed and emergent plants, and they are directly affected by water quality.

Fisheries research conducted on other lakes has shown that vascular aquatic plants provide multiple benefits to fish communities. These include: (1) substrate and cover for spawning (Loftus and Kushlan 1987); (2) habitat for foraging (Janacek 1988); and (3) protective habitat for larval and young adult stages of fish (Barnett and Schneider 1974, Conrow et al. 1990). In Lake Okeechobee, Furse and

Fox (1994) documented that bulrush, eelgrass, peppergrass, and *Hydrilla* provide important habitat for a variety of sport and forage fish (40 species total) in the near-shore area.

Furse and Fox (1994) noted that eelgrass, peppergrass, and spikerush provide important habitat in the lake for juvenile sport fish and small forage fish, and that bulrush, hydrilla, and pondweed account for most of the lake's recreational fishery value. Bulrush recreational value was four times higher than that estimated for any other component of the vegetation community in the near-shore area. Given these multiple functions, and the large-scale loss of both submerged aquatic vegetation, spikerush, and bulrush that has occurred in the last decade (details below), it is not surprising that in the most recent fisheries survey (October 1999), scientists noted significant declines in population densities and young age classes of economically important sport fish (FWC, unpublished data). It remains to be seen whether these populations have substantially recovered after a period of low lake stage (2000-01), followed by favorable moderate lake stage (2002) allowed for a dramatic recovery of the submerged plants and bulrush.

Although less studied, there is evidence that fish in the Lake's shoreline areas are directly impacted by large inputs of polluted water from agricultural areas adjacent to the lake. During large-scale algal blooms in the mid-1980s, it was reported that fish migrated away from the western shoreline (Jones 1987) to escape the effects of algal decay products (e.g., ammonia, and low D.O.). Hence, the fish were displaced from their foraging and nesting habitat into deeper water. Similarly, the FWC reports that during periods of intensive pumping of water from the Everglades Agricultural Area into the south end of the Lake, sport fish migrate away from areas of heavily stained (high color), low D.O. water.

If the modified hydrologic regime under the LOPP / CERP results in conditions that are more favorable for growth of submerged aquatic vegetation and bulrush in the near-shore zone of the lake, there will be substantial benefits to the lake's fish community. Water quality improvements that lead to a reduced frequency of algal blooms, and lower inputs of heavily stained, low D.O. water to the shoreline areas also will benefit the Lake's fishery.

IV. Lake Okeechobee Performance Measures

Based on the conceptual ecosystem model, a total of 20 water quality, biological, and hydrologic performance measures were derived (**Table 1**). The performance measures correspond, in general, to the boxes in the conceptual model. Five performance measures correspond to ecosystem stressors (**L1** – phosphorus loads, **L14** – exotic vegetation, **L18, L19** – extreme low and high stage), while the remainder relate to ecosystem values (**L11** – class I standards, **L16** – fish populations) or key attributes of the system that support those values. It is important to note that neither the conceptual model nor the list of performance measures includes wading birds, migratory water fowl, alligators, and snail kites. This is not to detract from their value in the ecosystem. They simply are being addressed as part of another restoration evaluation program – the RECOVER Monitoring and Assessment Program for CERP (USACE / SFWMD 2002) – as part of a regional sampling effort.

Table 1. Water quality, biological, and hydrologic performance measures for the Lake Restoration Assessment Plan, in support of the LOPP.

Code	Title	Restoration Goal
L1	Phosphorus loads to the Lake	Reduce external loads to the TMDL target of 140 metric tons P per year, as a long-term (5-yr) moving average
L2	Lake water phosphorus concentration	Reduce pelagic concentration to the TMDL goal of 40 ppb, as a long-term (5-yr) moving average
L3	Lake water TN:TP and DIN:SRP ratios	Increase pelagic TN:TP ratio to above 22:1 and increase DIN:SRP ratio to above 10:1, as long-term (5-yr) moving averages
L4	Algal nutrient limitation status	Re-establish conditions where the most common limiting nutrient is phosphorus, rather than nitrogen
L5	Ratio of diatoms to cyanobacteria (biomass)	Increase the ratio to above 1.5 at pelagic stations, as a long-term (5-yr) moving average
L6	Algal bloom frequency	Reduce frequency of pelagic blooms (chl *a* > 40 ppb) to < 5% of samples, as a long-term (5-yr) moving average
L7	Food web efficiency	Increase % edible phytoplankton; increase ratio of phytoplankton / bacterial productivity; increase ratio of zooplankton / phytoplankton biomass and productivity
L8	Water clarity	Increase water clarity, so a Secchi disk is visible on lake bottom (~1 m) in near-shore zone from May to September
L9	Near-shore phosphorus concentration	Reduce near-shore concentration to 40 ppb or lower, as a long-term (5-yr) moving average
L10	Littoral zone hydrology / nutrient status	Substantially reduce the frequency of transport of water from the open water region into the littoral zone, allowing the littoral zone to be primarily rainfall driven and nutrient-poor
L11	Lake Okeechobee Class I Water Quality Parameters	Consistently meet Class I standards in samples collected at Lake monitoring stations, except where exceedences are caused by natural conditions

Code	Title	Restoration Goal
L12	Submerged aquatic vegetation (SAV)	Maintain spatial extent of total SAV at >40,000 acres, and vascular SAV (eelgrass, peppergrass, and southern naiad) at >20,000 acres
L13	Emergent aquatic vegetation	Maintain spatial extent of shoreline bulrush at >5,000 acres. Maintain a substantially increased spatial extent of native, non-invasive (spikerush, beak rush, willow, sawgrass, button bush, pond apple, and Okeechobee gourd) short and long hydroperiod plants in the littoral zone
L14	Emergent and floating exotic vegetation	Substantially reduce the spatial extent of exotic (e.g., *Melaleuca*, torpedograss, water hyacinth, water lettuce) and nuisance (cattail) plants in the littoral and near-shore regions
L15	Macro-invertebrates, zooplankton, and forage fish	Increase and maintain the diversity of benthic macro-invertebrates; maintain healthy populations of zooplankton and forage fish; maintain healthy population of apple snails in the littoral zone
L16	Fish population density, age structure, and condition	Improve and maintain the density, age structure, and condition of black crappie, largemouth bass, and bream; reduce the relative abundance of gizzard shad, threadfin shad, and blue tilapia
L17	Shoreline organic berm	Reduce and then maintain a low frequency of occurrence and spatial extent of a berm of dead plant material and sediments along the western lakeshore
L18	Extremes in low lake stage	Maintain stages above 11 ft, and minimize frequency of stages below 12 ft for more than 12 consecutive months, except during natural drought events
L19	Extremes in high lake stage	Maintain stages below 17 ft, and minimize frequency of stages above 15 ft for more than 12 consecutive months
L20	Spring recession	Achieve a stage recession from near 15.5 ft in January to near 12.5 ft in June, with no reversal >0.5 ft/month during the recession, at least 3 out of every 5 years.

V. Monitoring and Assessment

V.1 Monitoring and Assessment Objectives

V.1.1 Hydrologic Assessment Objectives

The objective of hydrologic monitoring is to characterize the variations in water levels in Lake Okeechobee, so that the three hydrologic performance measures (L18, L19, L20) can be assessed. Hydrologic monitoring also considers volumes of water entering and exiting the system by surface water, precipitation, and evapotranspiration, so that nutrient budget calculations can be done.

V.1.2 Ecological Assessment Objectives

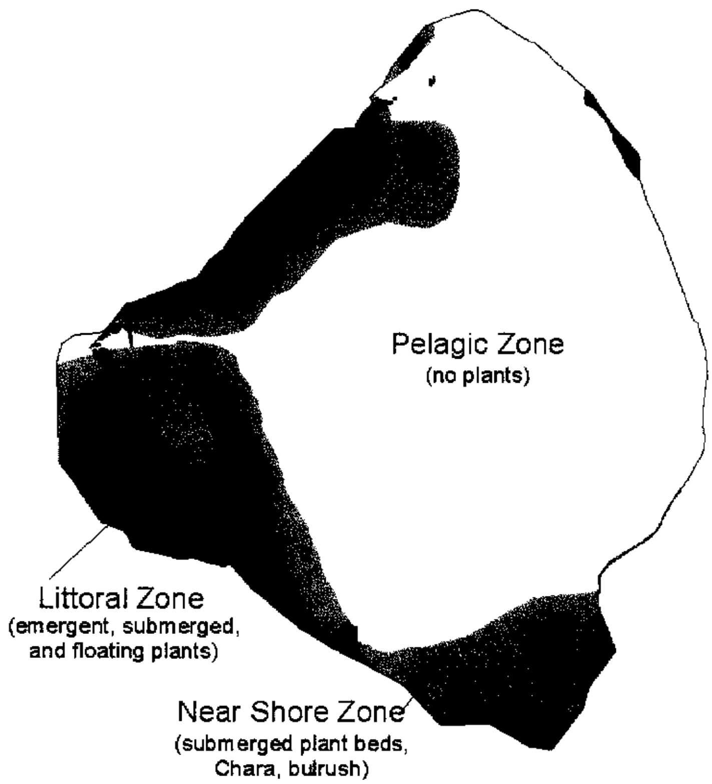
Ecological assessment is designed to evaluate changes in the health of the ecosystem that will be quantified by several performance measures (L12 to L17). Ecological assessment addresses a number of key questions related to the success of the Lake restoration programs: Will major indicators of ecosystem health respond as expected? How long after substantial phosphorus load reduction will we begin to see significant changes in health of the ecosystem, and how will this response be affected by changes in water levels, which may strongly influence the lake's biological communities and their ability to assimilate phosphorus? What range of water levels is necessary to sustain healthy communities of submerged and emergent plants? If unexpected ecosystem responses occur and the anticipated benefits to fish, wading birds, and other vertebrates are not achieved, what aspects of the underlying ecological processes are not operating as expected, and what management actions must be taken to correct them? The Restoration Assessment Plan is designed to address these key questions – i.e., in addition to simply providing information on success of the LOPP, to provide information that can be used to guide ongoing project implementation, in an adaptive assessment mode.

Ecological assessment focuses on three major physiographic regions within the lake – littoral, near-shore, pelagic (**Figure 3**) – and four ecological components – littoral zone emergent vegetation, near-shore submerged vegetation, forage fish and invertebrates, and higher trophic levels (e.g., sport fish). The littoral zone emergent vegetation is a diverse mosaic of native and exotic plants covering an area larger than 400 km^2. It provides nesting habitat and food resources for fish and wildlife, and the structure of the littoral vegetation community largely determines the extent to which it can provide these habitat values. Littoral vegetation structure is influenced both by hydroperiod and phosphorus loading from the lake's eutrophic pelagic region.

Submerged vegetation is a keystone component of the shallow near-shore area that occurs between the littoral zone proper and the deeper water pelagic zone of the lake. Submerged vegetation provides habitat for fish and wading birds, and it directly affects water quality by stabilizing sediments and providing a substrate for periphyton that actively removes phosphorus from the water column. At times and locations where submerged vegetation is very abundant, water is clear, and phytoplankton blooms are rare. Submerged vegetation spatial extent and biomass are expected to increase significantly as a result of projects under the LOPP.

Forage fish and invertebrates are included in the program because changes in their diversity and abundance, due to CERP, are anticipated to affect higher trophic levels, including sport fish. By including these lower trophic levels in the monitoring, both the habitat structure (vegetation distribution and abundance) and resource base for the higher trophic levels are addressed.

Figure 3. Three major physiographic regions of Lake Okeechobee that are included in this research and monitoring package, characterized on the basis of dominant types of primary producers (plants and algae).



V.1.3 Water Quality Assessment Objectives

Objectives for water quality assessment are complementary to those for the lake ecology. The aim is to determine to what extent projects implemented under the LOPP result in improvements in water quality of Lake Okeechobee, its major tributary inflows, and, ultimately, the quality of water that is available for distribution from the Lake to downstream resources. In regard to inputs of water to the lake, the major focus is on determining P loads, given the central role of excessive P in influencing the natural and societal values of the ecosystem. Stations for monitoring water inputs to the lake, and for load calculations associated with major nutrients, occur at all major tributaries entering and exiting the system.

In-lake water quality monitoring will evaluate cumulative water quality trends and conditions anticipated to result from the LOPP projects in the lake's watershed. The network of in-lake water quality stations has been optimized by the SFWMD to provide a spatially appropriate sampling of the major ecological zones of the ecosystem. Stations are clustered more densely at the interface region between the littoral and pelagic zones, due to greater heterogeneity in water quality, and are more sparsely clustered at mid-lake, where conditions are relatively homogeneous.

V.2 Monitoring and Assessment Methods

V.2.1 Hydrologic Assessment Methods

Hydrologic monitoring includes continuous flow measurement at all major tributary structures where water enters and exits the Lake, measurement of precipitation and evapotranspiration rates, and daily measurement of Lake surface elevation. This work is carried out by the SFWMD and USACE under existing state and federal mandates. Details of the monitoring can be found in James et al. (1995a,b). Data collected in the hydrologic assessment will be used to keep track of Lake conditions in respect to performance measures **L18 - L20** (*extremes in high and low stage, and spring recession*).

V.2.2 Ecological Assessment Methods

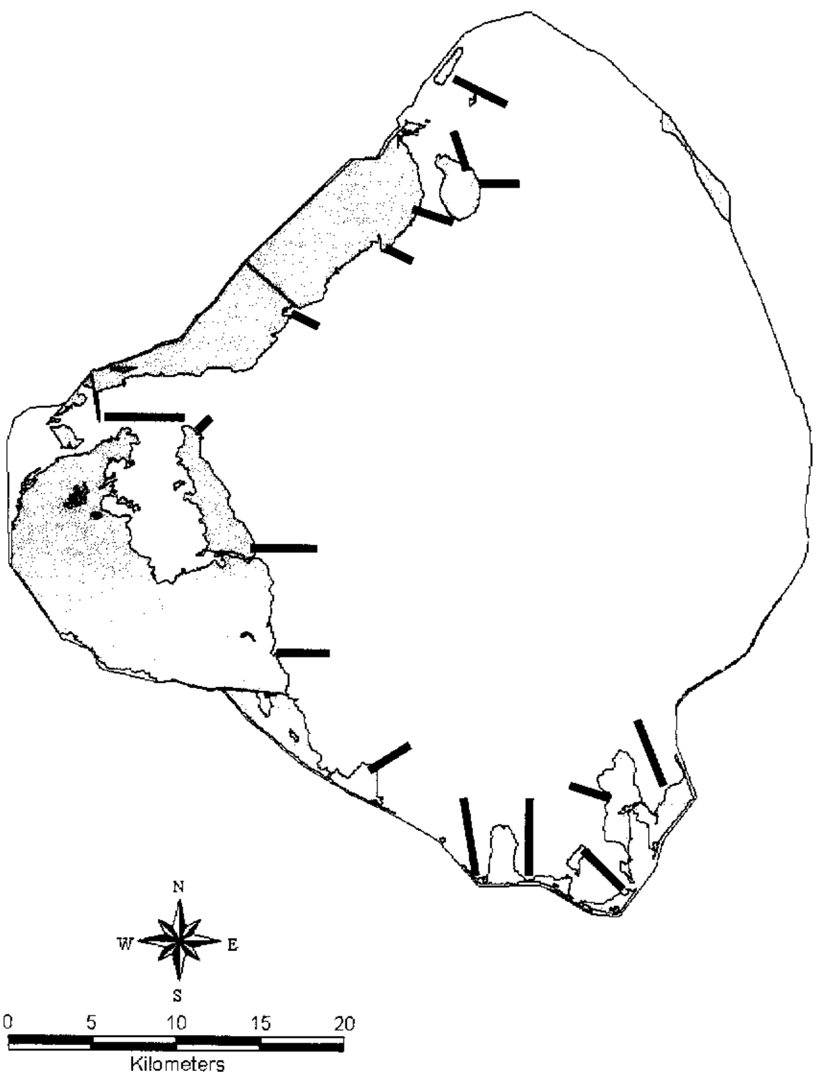
Emergent plant communities: The spatial distribution of native and exotic plants in the Lake's littoral zone is evaluated in an ongoing program by the SFWMD. Results are used to derive scores for performance measures **L13** (*native emergent vegetation*) and **L14** (*exotic emergent and floating vegetation)*. Emergent vegetation is photographed using high-resolution infrared aerial photography. Major vegetation classes (34 total) are delineated from the photographs using a stereoscope, and maps are developed in ARC/INFO. Extensive ground-truthing is carried out as a part of this process. The most recent mapping efforts have resulted in a classification accuracy of near 90%, which compares favorably with an accuracy of 60% that was associated with earlier maps developed from satellite imagery. At this time, biannual mapping is done to quantify the spatial distribution of torpedograss (*Panicum repens*) because this exotic plant is the focus of an ongoing multi-million dollar per year eradication program (SFWMD 2002). Biannual mapping is also done for bulrush (*Scirpus californicus*), a dynamic community that occurs along the interface between the pelagic and littoral zones. Mapping of the entire littoral vegetation community, a much more cost and labor intensive effort, is carried out approximately at six-year intervals. There are ongoing efforts by the SFWMD and NOAA to identify potential uses of hyper-spectral remote sensing as a more effective method for mapping the entire littoral zone of this large lake.

Associated with the lake's littoral zone, there is a berm of organic material along the western pelagic-littoral interface formed by dead submerged and emergent shoreline plants during years when there is sustained high water. Sampling of this berm will be done at six-year intervals to quantify performance measure **17** (*spatial extent of the berm*), in concert with the littoral vegetation mapping, and at a relatively low cost. During 2000-2001, the FWC and USACE, with support from the SFWMD, removed a portion of the berm and deposited it in a number of spoil islands along the lake shore that now are being planted with native vegetation, including willow and pond apple. Some islands also have developed healthy growth of Okeechobee gourd. Additional amounts of berm may be removed in 2003 or later, depending on when favorable conditions (low water level) occur. Long-term assessment of berm accumulation can be done in a manner that also will allow us to evaluate the longevity of removal projects.

Submerged plant communities: Submerged vegetation is monitored at two different spatial & temporal scales by the SFWMD. The results are used to quantify performance measure **L12** (*spatial extent of SAV*). Both methods rely on in-water sampling (rather than remote sensing) because remote sensing is unreliable when areas with submerged vegetation have water that is highly colored by dissolved organics or suspended solids. Remote sensing could drastically underestimate the spatial extent of submerged vegetation under these conditions and is biased towards higher estimates at times and locations when water clarity is high (e.g., during calm summers with low lake stage). In order to obtain quantitative estimates of plant species biomass, sampling is done at sites located along 16 transects in areas of the lake that support submerged plants (**Figure 4**).

On a quarterly basis (April, July, late September, and January), triplicate samples are collected at sites along each transect, starting at the shoreline and progressing lake ward until a site is reached with no plants. Plant sampling is done using a tool constructed of two standard garden rakes bolted together at mid-point to create a tong-like device. The degree of opening is constrained by placing a chain between the two handles so three replicate samplings with the device remove ~1 m^2 of bottom cover. The harvested material is sorted by species, stripped of epiphyton, and analyzed for dry mass.

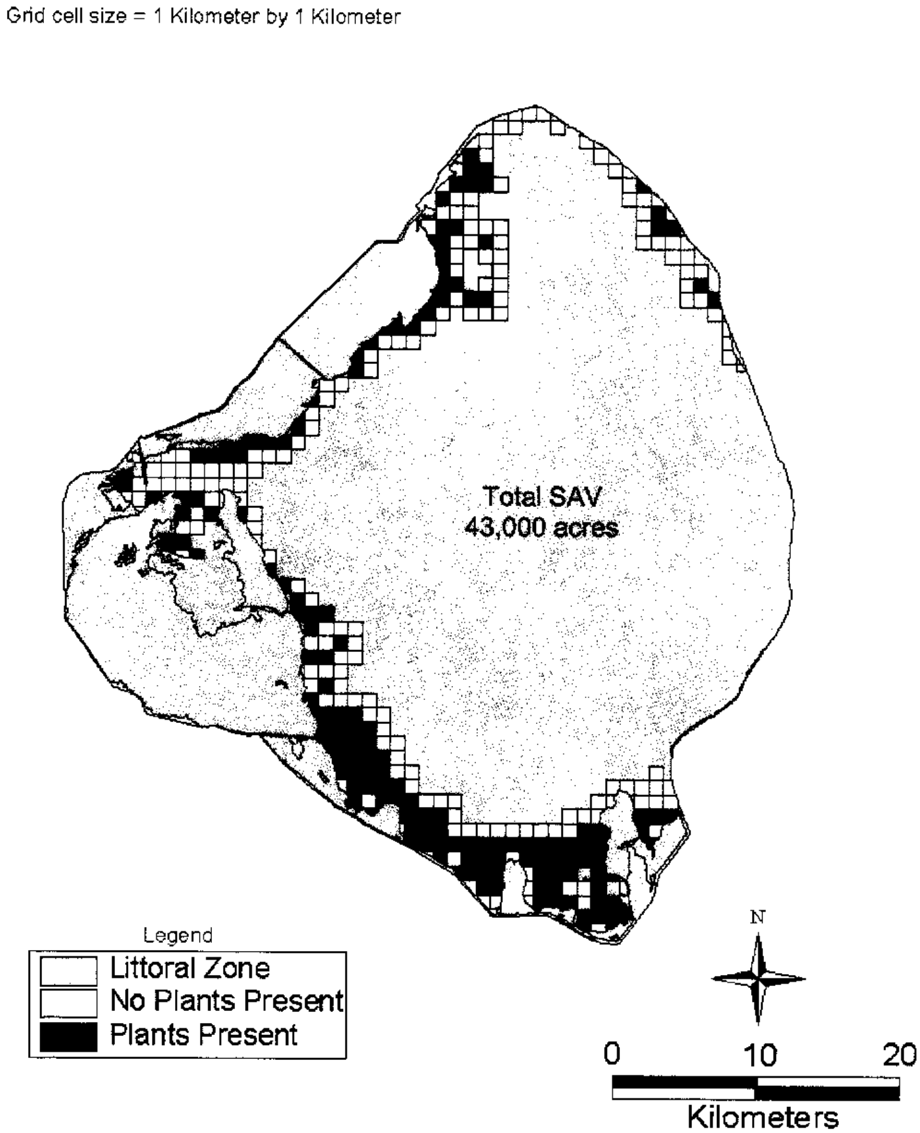
Figure 4. Map of Lake Okeechobee, showing the location of 16 transects for quarterly evaluation of submerged aquatic vegetation biomass, taxonomic structure, and water transparency. Plants are sampled at sites along each transect, starting at the shoreline and progressing lake ward until a site is reached where there are no plants. Current data from this project can be viewed at: www.sfwmd.gov/lo_statustrends/ecocond/surveys.html



At the same time that plant sampling is done along transects, measurements are made of total depth, Secchi depth, total suspended solids (TSS), non-volatile suspended solids (NVSS), and sediment type. Data from the SFWMD water quality monitoring program, which includes stations in the vicinity of all SAV transects, are used to identify other water quality conditions, including underwater irradiance and temperature profiles, color, chlorophyll *a*, total and soluble phosphorus, total and soluble nitrogen. The water chemistry data are important to understanding the light-attenuating properties of the water and explaining observed trends or patterns in submerged vegetation (Havens 2002). Samples also are collected from plants harvested at three locations (north, west, and south) of SAV collection, for determination of the biomass and nutrient content (N and P) of attached periphyton.

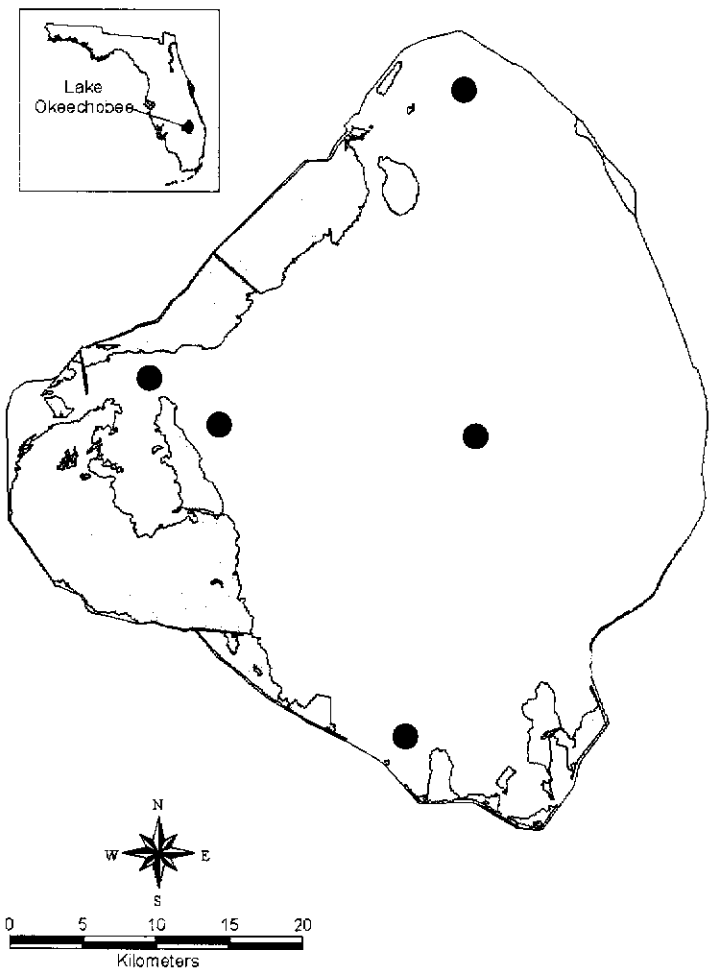
The spatial extent of submerged vegetation is determined by a mapping program (**Figure 5**) that is carried out between July and September, the period of peak biomass of this community. Rather than sampling random locations, the entire near-shore shelf area is sampled at a relatively fine spatial scale. GIS coverage of the lake surface is overlaid onto a rectangular grid of 1,000 x 1,000 m cells in ARC/INFO. GIS coverage of the littoral zone is laid onto the map, and common cells are clipped from the final coverage, as is the deeper central pelagic region. This results in a near-shore grid of approximately 750 sampling sites. Coordinates for the grid cell center-points are loaded into two Trimble Pathfinder GPS units (differentially corrected) for use in navigating to the sampling sites. A simple program is set up in each data logger so that users can enter information regarding water depth, Secchi depth, sediment type, presence vs. absence of vegetation taxa, and a qualitative estimate of overall plant biomass (sparse, moderate, dense). This yearly sampling starts in July or August and is completed in approximately 3-4 weeks. Sample runs begin near the shoreline and proceed lakeward along a row of cells until a site is encountered with no SAV. The boat operator navigates to the sites by GPS, where water depth is measured with a calibrated plastic rod and Secchi depth is measured with a 20-cm black and white disk. Plant sampling is as described above. Plants are placed into a plastic tray and sorted by species, and the information described above is entered into a data logger. Sediment type is determined by inspection of material brought up in the rakes or by observation from the boat where water transparency is good. Sampling with this method is possible up to a maximal depth of approximately 2 m. Field data are downloaded from the GPS logger into ARC/INFO, where maps are developed for each of the measured attributes and spatial extents are calculated in hectares. It is assumed that data collected at the center-point of a grid cell represents that of the entire cell. While this may introduce error into the results, it is a necessary assumption given the large spatial scale of sampling.

Figure 5. Map of Lake Okeechobee, showing the 1,000 x 1,000 sampling grid for yearly evaluation of SAV spatial extent. This map shows results of the July 2002 survey. Maps of this type are produced for each dominant plant species. Current data from this project can be viewed at: www.sfwmd.gov/lo_statustrends/ecocond/savmaps.html



Phytoplankton, Bacteria, and Food Web Efficiency: The biomass and taxonomic composition of phytoplankton is quantified from quarterly data collected at five open-water stations that taken together, characterize the range of plankton communities that occur in the ecosystem (**Figure 6**). The sampling stations (L001, L005, LZ40, POLE3S, and FEBOUT) also are routine SFWMD water quality monitoring locations. At these stations, zooplankton also are collected (see the next section), and measurements are made of phytoplankton primary productivity, nutrient limitation status, bacterial biomass and productivity, and zooplankton productivity. The results are used to quantify several performance measures (**L4** – nutrient limitation status, **L5** – ratio of diatoms to cyanobacteria, **L7** – plankton food web efficiency).

Figure 6. Sampling stations for quarterly assessment of phytoplankton biomass, taxonomic composition, and productivity, nutrient-limitation status, bacterial biomass and productivity, and zooplankton biomass, taxonomic composition, and productivity.



Water samples for phytoplankton and bacterial analyses are collected with a 5-cm diameter PVC tube, that is lowered into the water column to within 0.25 m of the lake bottom, after-which the bottom end is closed with a rubber stopper. This integrated sample of the entire water column is released into a 20-L plastic carboy, from which sub-samples are withdrawn and preserved for enumeration of phytoplankton, protozoa, and bacteria. Phytoplankton samples are preserved with acid Lugol's solution (for counting large phytoplankton) or buffered gluteraldehyde (for counting nano-flagellates). Bacterial samples are preserved with 0.2-µm filtered formalin. The preserved samples are held in the dark under refrigerated conditions until they are processed. The remaining water in the carboys is taken back to the lab, under tarps to prevent direct exposure to sunlight, for use in nutrient limitation bioassays and experiments to measure rates of bacterial, phytoplankton, and zooplankton productivity.

Phytoplankton biomass and taxonomic structure. Three different methods are used to enumerate phytoplankton, depending on the size of cells being considered. For pico-phytoplankton (0.2 to 2 µm diameter), counts are done within 24 hrs of collection. Water samples are removed from the carboys and diluted 1:10 or 1:100 (depending on time of year) with 0.2 µm filtered de-ionized water. A small aliquot (1 ml) of the diluted sample is filtered onto a black 0.2 µm polycarbonate filter under low vacuum, and a slide is prepared for counting the cells by their auto-fluorescence, using an epi-fluorescent microscope at 1,000X magnification. Pico-phytoplankton cell volumes do not vary considerably from one season to another, so that biomass can be estimated from counts using a standard conversion factor provided by Work et al. (2002). For nano-flagellates, cells are stained with Primulin and counted with an epi-fluorescent microscope using the method of Caron (1983). Micro-phytoplankton (larger algal cells and colonies, typically >5 µm in size, and up to 100 µm or higher) are settled in sedimentation chambers for 24 hrs and counted with the inverted microscope method (Lund et al. 1958). For all of these methods, random fields are counted until 200 cells have been enumerated; this is done to maintain a consistent counting precision for samples with high vs. low densities of cells (Lund et al. 1958).

Bacterial biomass. Bacterial samples are diluted to a reasonable density (1:10 or 1:100) for counting with 0.2 µm filtered and autoclaved deionized water and the sub-sampled. Sub-samples are filtered onto 0.2 µm black Nucleopore polycarbonate filters and stained with acridine orange. Bacteria are enumerated by using epifluorescent microscopy (1,000X magnification). Randomly selected fields are scanned until at least 400 cells are enumerated. Cells are measured (25 cells per sub-sample) with an ocular micrometer. Biovolume estimates are obtained by multiplying measured dimensions for each bacterial cell morphology (rod or cocci) by dimension to biovolume conversion equations (Wetzel and Likens 1991). Biomass is estimated from biovolume assuming unit density.

Phytoplankton productivity. Phytoplankton primary productivity is measured using a standard ^{14}C tracer method, and a photosynthetron (reference) that allows for simultaneous measurements of uptake rates over a range of irradiances that encompass those observed in the water column of the lake. The radioisotope is added to 20-ml glass vials of unfiltered lake water as ^{14}C sodium bicarbonate, and 1 hr incubations are done at ambient temperature. Following incubation, the samples are spiked with concentrated HCl to drive off any non-incorporated ^{14}C, and held in a fume hood overnight. The samples then are counted on a liquid scintillation counter, with correction for quenching and background radiation. Counts are used to calculate rates of photosynthetic carbon uptake, based on the method of Vollenweider (1974). These uptake rates represent gross photosynthesis, because they include both the ^{14}C that has been incorporated into the algal cells, and any ^{14}C labelled dissolved organic carbon that is excreted during the incubation period. Results from the phytoplankton production measurements are used to generate photosynthesis: irradiance curves which, when coupled with field data regarding underwater irradiance profiles at the sampling sites and photoperiod, allow for the calculation of productivity on a per square meter basis (Jassby and Platt 1976).

Bacterial productivity. Bacterial productivity is estimated using ^{3}H-thymidine incorporation (modified from Bell 1993). Replicate sub-samples from each station are spiked with ^{3}H-thymidine and incubated at *in situ* temperature for 1 h. At the end of the incubation, activity is stopped with the addition of chilled 50% trichloroacetic acid (5% final volume). Samples are placed on ice for 15 min and filtered under vacuum (~100 mm Hg) onto 0.2 μm polycarbonate filters. These filters are placed into 7-ml plastic vials with scintillation cocktail, and ^{3}H-thymidine incorporation is measured by a liquid scintillation counter. The method also includes simultaneous measurements of bacterial numbers and ^{3}H-thymidine incorporation at fixed time intervals over a period of 24 hrs. The results are used to convert thymidine uptake rates into rates of carbon uptake, on a per square meter basis. Detailed methods are provided in Scavia and Laird (1987).

Nutrient limitation bioassays. Nutrient bioassays are performed in order to determine whether N, P, N+P, light, or some other unknown factor is limiting to the growth of phytoplankton in the lake's open water region. Integrated water from the 5 plankton sampling stations (above) is used, so that the analysis is done with natural phytoplankton assemblages.

Assay methodology is generally similar to that used by Aldridge et al. (1995), except that a light gradient is included as an independent fixed variable in addition to the variables of macronutrient type (N, P, or N+P). A 150 ml aliquot of water from each site is dispensed into triplicate 250 ml flasks and either non-treated (control and light gradient flasks) or spiked with either N (as nitrate, 400 $\mu g\ N\ L^{-1}$), P (as phosphate, 40 $\mu g\ P\ L^{-1}$) or N+P. The light gradient covers the range from 12 to 240 $\mu mol\ m^{-2}\ s^{-1}$ in 4 approximately equal increments. Assays are conducted over 48 hours in incubators set to reflect ambient environmental temperature and photoperiod. Changes in algal biomass are estimated as changes in net *in-vivo* fluorescence of chlorophyll (IVF). To minimize the effects of circadian rhythms, and exposure to light on IVF (Berman, 1972), fluorescence readings are taken near the end of each dark cycle. IVF is measured at the start of the assay, and after 24 and 48 hours of incubation. Assays are not carried beyond 48 hours to limit the potential confounding effects of species succession and the onset of epiphytic growth on the walls of the experimental flasks (Schelske 1984, Carignan and Planas 1994, Dodds and Priscu 1990). Determination of limitation status is done using analysis of variance (ANOVA) followed by Scheffe's multiple comparison procedure (SAS, 1990). The limiting parameter (light, N, P, or N+P) is defined as the parameter in each assay, which that upon experimental enhancement, results in a statistically significant increase in IVF after 48 hours of incubation.

Plankton food web efficiency. The efficiency of plankton food webs (performance measure **L7**) is estimated in several ways. First, it is gauged by the ratio of phytoplankton: zooplankton biomass (BZ / BP). Where this ratio is low, there typically is evidence that the community is stressed, resulting in reduced transfer of photosynthetic carbon to the zooplankton grazers (Gliwicz 1969, Hillbricht-Ilkowska 1977, Havens 1992). Second, it is gauged by the ratio of bacterial productivity: phytoplankton productivity (PB / PP). This ratio tends to be higher in lakes where nutrient-enrichment has led to dominance by inedible blue-green algae, which release considerable amounts of organic carbon into the water, stimulating bacterial growth (Weisse and Stockner 1992, Kamjunke et al. 1997). Third, the efficiency can be directly measured using a radio-tracer method developed by Ducklow et al. (1986) and modified by Koshikawa et al. (1996) for work in the Sea of Japan and by Havens et al. (2000) for use in Lake Okeechobee. Samples of natural plankton, including phytoplankton and zooplankton, are placed into 4-L glass jars, and spiked with ^{14}C bicarbonate (dissolved inorganic carbon, DIC). The bottles are incubated for 4-hrs at a temperature and irradiance approximating that found in the lake, and then the water is sequentially size-fractionated through filters of 200, 40, 20, 2, and 0.2 μm porosity. The filters, containing plankton of different size classes from known volumes of water, are placed into scintillation cocktail and counted for their radioactivity. Food web efficiency, in terms of transfer of carbon from the base of the web (phytoplankton) to the top (large zooplankton), is calculated as the ratio of activity in the

200 μm size fraction to total activity of all size fractions summed. The entire procedure takes approximately 6 hrs, and provides a repeatable, low-cost method for estimating transfer efficiency. Results are very comparable to those obtained with considerably more costly and time-consuming methods to directly measure rates of carbon transfer through the food web (Havens et al. 2000). Data from the intermediate size fractions can be used to explain observed results. For example, under current conditions (small zooplankton and large inedible blue-green algae), most of the activity accumulates in the 20 and 40 μm size fractions, and is not passed upwards through the food web.

Zooplankton and Macro-Invertebrates: Zooplankton is sampled on a quarterly basis in an ongoing program by the SFWMD at the same open-water locations as phytoplankton (**Figure 6**), in order to quantify performance measures **L7** (*plankton food web efficiency*) and **L15** (*macro-invertebrates, zooplankton, and forage fish*). A continuous data set for zooplankton exists from August 1994 to present. Macro-zooplankton (cladocerans and copepods) is sampled by triplicate vertical tows of a Wisconsin-type plankton net (30.5 cm diameter, 153 μm mesh). Samples are enumerated and data are obtained regarding both numeric densities and dry weight biomass of all species. Biomass estimates are derived from species length-weight relationships that have been developed for the lake over the last 5 years. Micro-zooplankton (rotifers and nauplii) is sampled with a PVC tube that collects an integrated sample that is passed through a 40 μm plankton net to collect animals. These are preserved in formalin-sucrose solution, enumerated, and biovolumes are calculated using appropriate geometric formulae and converted to fresh weights and dry weights. Whole water samples collected with the PVC tube are preserved with Lugol's solution and enumerated at 500X magnification for enumeration of micro-phytoplankton (algae >20 μm), which include the taxa that form algal blooms.

Aquatic macro-invertebrate communities of the Lake Okeechobee must be sampled in order to quantify performance measure **L15** (*macro-invertebrates, zooplankton, and forage fish*) Macro-invertebrates in the pelagic zone were sampled by the FWC on a quarterly (February, May, August, November) basis in 1987-88 and then semi-annually (January and July) through 1996. Since 1996, invertebrate communities have been sampled intermittently, with the last collection occurring in June 2000. Sampling was conducted at 18 fixed sites, with six sites each in mud (northern and mid-lake), sand (western), and peat (southern) habitat zones. Three pseudo-replicate samples were collected at each of the 18 sites during every sampling event, yielding 18 samples per habitat zone and a total of 54 samples. Samples were collected with a petite ponar dredge. Physical-chemical measurements obtained at the time of sampling included 0.5 m incremental profiles of water temperature and dissolved oxygen concentration.

In the littoral zone, macro-invertebrate sampling was conducted in three study areas from 1987-1990 and along a transect near Indian Prairie canal from 1991-1994. Intermittent sampling was conducted at several locations from 1995-2000. Sampling was stratified by vegetation type. Invertebrate communities inhabiting *Eleocharis* sp., *Hydrilla verticillata*, *Nymphaea* sp., *Panicum repens*, *Pontederia cordata*, *Potamogeton illinoensis*, *Scirpus* sp., *Typha* sp., and *Vallisneria americana* were sampled at various times. Invertebrate communities of submersed and emergent macrophytes were sampled using a modified Hess sampler. Invertebrate communities inhabiting sediments beneath macrophytes were sampled using a corer. Three pseudo-replicate samples were collected from both the macrophyte and bottom habitats at each sampling site during every collection. Physical-chemical measurements obtained at the time of sampling included 0.5 m incremental profiles of water temperature and dissolved oxygen concentration.

A Lake Okeechobee macro-invertebrate monitoring program needs to be established. It should use sites and methods established during the FWC studies, because this will make data collected during different time periods more comparable. Ideally, the 18 sampling sites would be sampled on a quarterly basis during months corresponding to FWC collections. Permanent monitoring locations also should be established in both the northwest and western littoral zones of the lake. Littoral zone invertebrate communities inhabiting macrophytes and sediments beneath macrophytes should be sampled using FWC methods to provide for some continuity in the data. Given the importance of this information to evaluating the Lake's recovery from excessive phosphorus inputs, it is recommended as a new monitoring effort, requiring dedicated funding that presently is not available. A request has been made to have this project funded by the CERP RECOVER program, but if this does not occur, it should be considered as a high priority item for funding under the LOPP. An estimated cost of sampling is $75,000 per year.

The SFWMD currently samples macro-invertebrates at the extreme south end of the Lake, in the vicinity of the S2 pump station, which delivers water to the Lake from the Everglades Agricultural Area during flood control "back-pumping" events. At this time, sampling is occurring as part of a 2-year study to evaluate impacts of back-pumping that occurred during summer 2001. However, it is recommended that permanent sampling sites be located near this site, to monitor changes in the composition of the macro-invertebrate community (expectation – decreased relative abundance of pollution tolerant species) over time, as the frequency of back-pumping is reduced by regional flood control / ecosystem restoration projects. Location of sample sites, frequency of sampling, and sampling methods (e.g., artificial substrates vs. natural samples) are under consideration at this time.

Another important component of the Lake's food web that responds to changes in degree of eutrophication and Lake hydro-pattern is the forage fish community (a component of performance measure **L15**). At this time, the plan is to have these animals sampled as part of a regional forage fish-monitoring program under CERP RECOVER.

Fisheries: Performance measures related to the lake's fishery (**L16**, *fish population density, age structure, and condition*) are critical for determining success of the restoration program, given the importance of this particular resource. There is ongoing sampling, on a yearly basis, by the FWC to determine the condition and population structure of largemouth bass, the lake's most well-known sport fish. In this program, a total of 22 fixed sampling regions have been established around the entire perimeter of the lake. Triplicate samples are done in each zone during October by 15 minute electrofishing transects. All largemouth bass encountered during the electrofishing operation are weighed, measured, and released at the area of capture. Ancillary data, including water temperature, dissolved oxygen, pH, turbidity, conductivity, and sediment/aquatic plant type, are recorded in the sampling regions. Given the restricted focus of this program on just one species and the qualitative sampling methods, it is recommended that funds be made available for a comprehensive yearly sampling program. Methods are anticipated to include block netting at four distinct habitat types in the near-shore and littoral regions and trawl sampling in the open lake. A request has been made to have this project funded by the CERP RECOVER program, but if this does not occur, it should be considered a high priority item for funding under LOPP. An estimate cost of sampling is $100,000 per year. To ensure consistency in methods, it is recommended that this work be carried out by the FWC.

V.2.3 Water Quality Sampling Methods

A water quality and load monitoring program for all inflows to Lake Okeechobee has been carried out by the SFWMD since the early 1970s (**Figure 7**). Data from that program will be used to quantify performance measure **L1** (*phosphorus loads to the lake*). A detailed description of the monitoring program is provided in James et al. (1995b). For in-lake monitoring, the existing water quality-monitoring network (**Figure 8, Table 2**) administered by the SFWMD also is adequate to meet the goals and objectives of this Plan, and in particular, to collect the data needed to evaluate performance measures **L2** (*pelagic phosphorus concentrations*), **L3** (*pelagic nitrogen: phosphorus ratios*), **L6** (*pelagic algal bloom frequency*), **L8** (*near-shore water clarity*), **L9** and **L10** (*near-shore and littoral phosphorus concentrations*), and **L11** (*class I water quality parameters*). Data from pelagic stations L001-L008 provide information needed to evaluate progress towards the TMDL goal of 40 ppb, as a long-term average concentration at those stations. Data from near-shore and littoral stations will provide information needed to evaluate whether those stations display substantial reductions in phosphorus, as expected, under reduced external loading and lower lake stages. Details regarding this monitoring program are provided in James et al. (1995b).

Table 2. In-lake water quality monitoring for the Lake Restoration Assessment Plan.

Parameters	Sites	Frequency
Dissolved oxygen, conductivity, pH, temperature, alkalinity, turbidity, TSS, color, TP, TKN, NH3, NO2+3, Silicate, SRP, SO4, Chloride, Chlorophyll *a*	30	Monthly
Cd, Cu, Zn, Fe, Ca, Mg	30	4/year
Pore-water P, N, dry and wet bulk density, ash, Fe, Mn	~170	Every 10 years

Figure 7. Map of Lake Okeechobee, showing the locations of 32 tributary water quality monitoring stations (numbers in circles) for the Lake Restoration Assessment Program of the LOPP. These stations are those required for determining the Lake's external phosphorus loading rate, one of the priority ecosystem performance measures in this Plan. Structure names, sample collection methods, and periods of record are provided in Table 3. The eight long-term pelagic water quality monitoring stations (L001-L008) also are shown for reference.

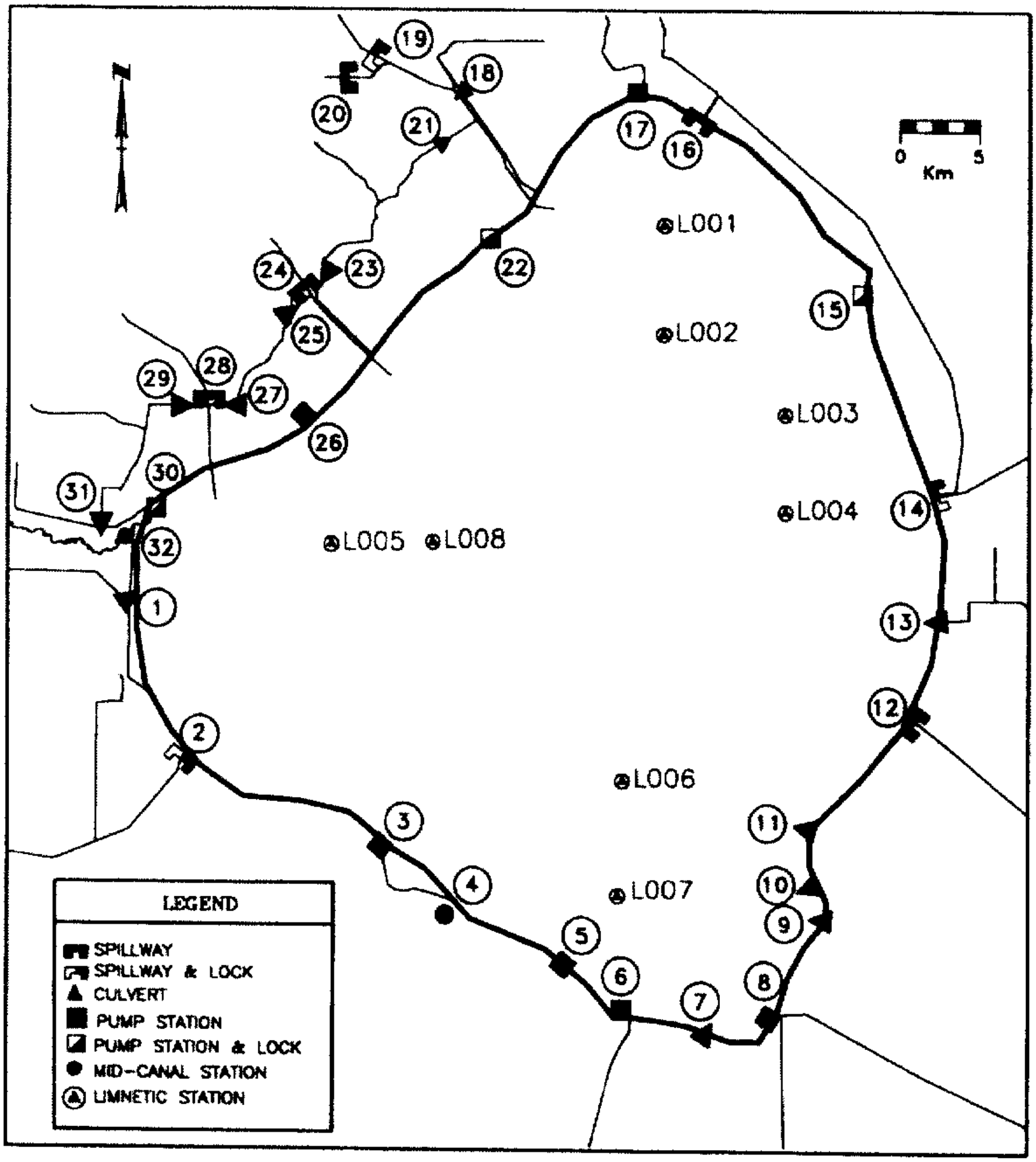


Figure 8. Map of Lake Okeechobee, showing names and locations of 30 in-lake water quality monitoring stations. In this map the three major physiographic regions (open water, near-shore, littoral) shown in Figure 3 are further divided into sub-regions that have significantly different water quality characteristics. The open water regions (light blue) also can display spatial variation in water quality (Phlips et al. 1993), but the extent to which this occurs depends strongly on lake stage. That region is not sub-divided in this particular map, but this heterogeneity needs to be taken into consideration in data analysis. The stations are sampled monthly from November to April, and twice monthly from May to October. Samples are near-surface grabs.

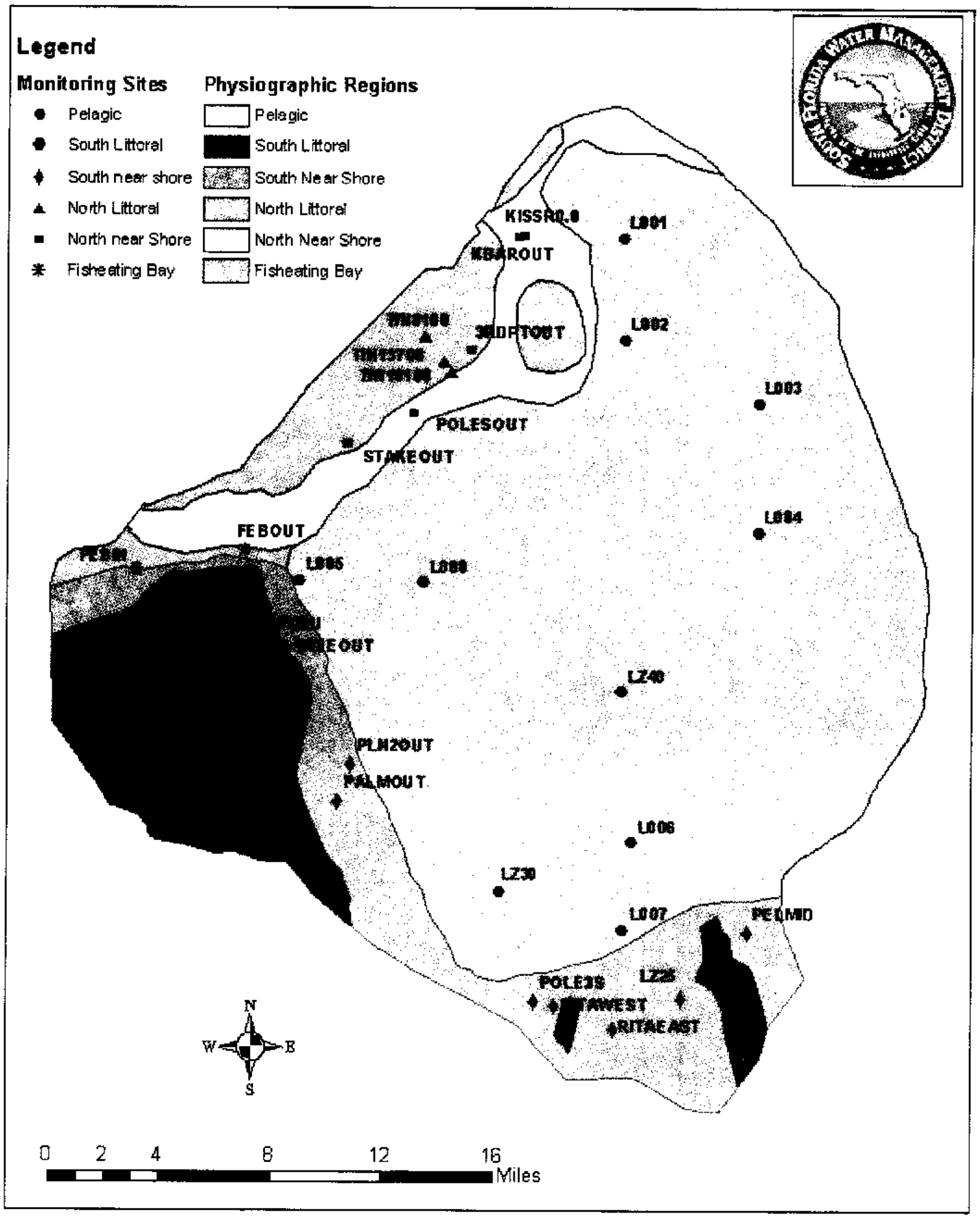


Table 3. Lake Okeechobee inflow / outflow monitoring stations, corresponding to the numbered locations on the map in Figure 7, with information on data collection methods for flow and total phosphorus concentrations. For flow record method, L = daily written log, R = recorder, S = stage recorder, and R/R = rainfall/runoff curve. For water sample method, G = grab sample, and A = autosampler. For water sample frequency, M = monthly, and B = biweekly.

Map Number	Station Name	Flow record method	Water sample method	Water sample frequency
1	Culvert 5	L	G	M
2	S-77	R	G	B
3	S-4	S	G	B
4	Industrial Canal	S	G	B
5	S-236	L	G	B
6	S-3	R	G/A	B
7	Culvert 4A	L	G	B
8	S-2	R	G/A	B
9	Culvert 12	L	G	B
10	Culvert 12A	L	G	B
11	Culvert 10	L	G	B
12	Hurricane Gate S-5	R	G	B
13	Culvert 10A	R	G	B
14	S-308	R	G	B
15	S-135	L	G	B
16	S-191	L	G/A	B
17	S-133	R	G	B
18	S-154	L	G/A	B
19	S-65E	R	G/A	B
20	S-84	R	G	B
21	L-59E	R/R	G	M
22	S-127	L	G	B
23	L-59W	R/R	G	M
24	S-72	R	G	B
25	L-60E	R/R	G	M

26	S-129	L	G	B
27	L-60W	R/R	G	M
28	S-71	R	G	B
29	L-61E	R/R	G	M
30	S-131	L	G	B
31	L-61W	R/R	G	M
32	Fisheating Creek	S	G	B

VI. Key Uncertainties / Research Questions

A rigorous program of scientific research, including long-term observations and controlled cause-effect experiments, is the foundation of the Lake Restoration Assessment Plan. However, key uncertainties remain. Addressing uncertainties that significantly affect our ability to predict Lake responses to the LOPP projects are an integral part of the program. In the Monitoring and Assessment Plan for CERP, a number of key uncertainties are identified for the Lake. They focus primarily on responses of higher trophic levels (fish, wading birds, alligators) to changes in hydro-pattern. The key uncertainties described here deal with responses of the Lake to phosphorus load reduction and exotic plant control, the two primary areas of focus in the LOPP. In each case, a brief description of the issue and recommended research approach is provided. It is envisioned that for these projects, detailed work plans will be developed, peer-reviewed, and then prioritized for available funding. One of the projects described below is ongoing, with Legislative funding from 2002.

Research Project Summaries:

1. ***Question: To what extent does submerged vegetation act as a net sink for phosphorus in the Lake, and to what extent could lake P assimilative capacity be increased by expanded coverage of submerged vegetation?***

Justification

With a reduction in damaging high water levels expected to occur under the LOPP / CERP, the submerged plant community in Lake Okeechobee should dramatically increase, both in terms of biomass and spatial extent. Submerged vegetation, and its associated periphyton, is known to be a strong sink for phosphorus, due to a variety of mechanisms; these include direct uptake of soluble phosphorus, physical stabilization of sediments, oxygenation of sediments causing precipitation of soluble phosphorus with iron, and co-precipitation of phosphorus with calcium at high pH (see literature citations in Section III).

The extent to which these processes may come into play in this large, wind-driven subtropical lake is not well understood, as most research with this subject has been done in smaller temperate lakes. A research program is underway to address this area of uncertainty. The research results will feed directly into development of a linked hydrodynamic – water quality – submerged vegetation model of the lake that presently is under development to meet a mandate of the LOPP.

Scope of Work

An array of experimental and observational work has been in progress by the SFWMD since spring 2002 to address this issue. The work is being done in-house by SFWMD scientists, including one post-doctoral scientist who is an expert in phosphorus processing by submerged plants. Controlled experiments are being done with 1 m^3 flow-through lakeshore tanks, to evaluate net effects of submerged vegetation on phosphorus concentrations in lake water. Microcosm studies with phosphorus radioisotopes are being done to examine the pathways for phosphorus uptake and processing by the plant community. Field studies are being done to construct phosphorus mass balances for submerged plant beds, and dye tracer studies are being done to evaluate the degree of interaction between dense beds and surrounding lake water. Funding for this project was provided by the Florida Legislature in 2002. The expected completion date is July 2004.

2. ***Question: To what extent do benthic algae act as a net sink for phosphorus in the Lake, and to what extent could lake P assimilative capacity be increased by expanded coverage of benthic algal mat?***

Justification

In regions of the lake of intermediate depth (1-3 m), benthic algae can form a thick carpet over the bottom sediments during the summer months, as long as water levels are low enough to permit light to reach the lake bottom. Benthic algae have the potential to substantially reduce concentrations of P and N in the overlying water column, by taking up nutrients from the water, and by preventing nutrient fluxes from the underlying sediments (reviewed by Havens et al. 2001). Under the LOPP / CERP, lower water levels are expected in the lake. This could result in an increased density and spatial extent of benthic algae, and an increase in the Lake's capacity to assimilate nutrients. However, it is difficult to predict the extent to which this might occur, due to a lack of information on light requirements of the algae and their P and N uptake capabilities. Existing data in the literature are from temperate lakes, and are not directly applicable to this subtropical system. The information resulting from this research will be used in calibration of the Lake water quality model, and could have direct application for evaluating Lake responses to the LOPP and CERP, and in any future re-evaluation of the Lake phosphorus TMDL. A scope of work for this project has not been developed.

3. ***Question: What is the magnitude and seasonal / spatial variation in the major processes of the Lake's nitrogen cycle (e.g., denitrification, nitrification, nitrogen fixation?***

Justification

As a result of decades of excessive P loading, the primary limiting nutrient for phytoplankton in Lake Okeechobee is N, when underwater light conditions are suitable for net growth (Aldridge et al. 1995, Havens 1994). This means that until P concentrations are substantially reduced, N availability (and underwater light) will determine the biomass of bloom-forming algae in the water column. Our ability to accurately model lake responses to LOPP projects therefore depends on good information on the N cycle, which presently is lacking. The existing lake water quality models use literature data from temperate lakes, and some information on N fixation (Phlips and Ihnat 1995) from Lake Okeechobee. The results of the additional research will be used in calibration of the Lake water quality model, and could have direct application for evaluating lake responses to the LOPP and CERP, and in any future re-evaluation of the Lake phosphorus TMDL. A scope of work has not been developed for this project.

4. ***Question: How do toxic blue-green algae respond to changes in underwater light availability, water column stability, and changes in availability of dissolved inorganic nitrogen and phosphorus?***

Justification

The algal community in the water column of Lake Okeechobee is dominated by blue-greens (cyanobacteria), including species known to produce toxins (Cichra et al. 1995, Havens et al. 2002a). The abundance of these algae appears to be controlled primarily by the availability of light, water column stability, and concentrations of soluble N. Projects under the LOPP and CERP have the potential to influence these attributes. At this time our understanding of how the toxic blue-greens might respond is based on observational data (Havens et al. 1998), so that uncertainty is quite high. Controlled experiments are needed to establish cause-effect relationships between biomass of toxin producing blue-greens and light / nutrient conditions. A scope of work has not been developed for this project.

5. *Question: How accurate are the various parameters used in the Lake Okeechobee water quality model – in particular those that have a substantial effect on model results?*

Justification

The Lake Okeechobee water quality model, including the linked hydrodynamic – water quality – submerged vegetation model under development, will be calibrated and validated with extensive data collected on the Lake ecosystem from the late 1980s to present by scientists from the University of Florida (e.g., Phlips et al. 1995, Reddy et al. 1995) and SFWMD. However, a number of key model parameters are based on literature data from other lakes, mainly lakes in temperate regions. It is important to determine if these parameters are being accurately represented if we are to have a high degree of confidence in model results. According to James et al. (1997), key parameters affecting model results (and for which better data are needed) include: particle settling velocities, seston C:N:P ratios, and mineralization rates of dissolved organic P in water and sediments. These attributes can be measured using a combination of field and laboratory experiments. A scope of work has not been developed.

As noted by Professor Claire Schelske, an independent reviewer of this document, another critical area of uncertainty is in regard to the lake's sediment inventory and sediment accumulation rate. Gathering that information is important to obtaining correct sediment loss terms in the Lake Okeechobee Water Quality Model. A project to obtain the necessary data would include collection of sediment cores from a number of sites across the lake's mud zone, sectioning those cores at fine intervals (e.g., 1 cm or less), and then calculating rates of sediment and phosphorus accumulation across the spatial extent of the mud zone based on radioisotope dating of the sections and analysis of sediment phosphorus content and bulk density.

6. *Question: To what extent does the spatial distribution of mud sediments and sediment phosphorus change from year to year in the lake?*

Justification

The spatial extent of mud sediments and its P content is an important factor in determining the magnitude of internal P loading, and is a key aspect to consider when evaluating in-lake restoration options (e.g., sediment removal or chemical treatment). Up to now sediments have been mapped at 10-year intervals. Significant changes in distribution and P content have been documented (Fisher et al. 2001), but we do not know if these represent long-term directional changes, or stochastic "noise" that occurs from year to year in this highly dynamic wind-driven system. A network of sediment sampling stations (perhaps three or four mid-lake to shoreline transects) should be established, for sampling of mud thickness and P content at yearly (or perhaps even twice-yearly) intervals. A scope of work has not been developed, but this is a relatively simple project that could be carried out by experts at the SFWMD with additional funding for a field technician and laboratory support services.

VII. Data Storage and Retrieval

All data collected by the SFWMD on Lake Okeechobee are stored in Oracle databases, and are available to other agencies and the general public. The SFWMD water quality database can be accessed via the Internet at www.sfwmd.gov. Ecological data from the Lake, which presently include submerged vegetation, plankton, macro-invertebrates, and results from miscellaneous controlled experiments, are maintained in the Lake Okeechobee Ecological Database, which is maintained by staff in the Lake Okeechobee Department of the SFWMD. This database has a user-friendly graphical user interface, and in the near future, should be web-enabled, for browsing and data retrieval over the Internet. All data that are input to these databases undergo rigorous QA/QC, following standard guidelines of the SFWMD, and have standardized accompanying meta-data files.

VIII. Evaluation and Reporting Protocol

In addition to collecting appropriate data and storing it in a readily accessible and stable form, the manner of data evaluation and reporting is a critical aspect of the Lake Restoration Assessment Plan. In this Plan, a number of specific resource performance measures have been identified, some with very specific goals (e.g., pelagic total P concentration of 40 ppb). For some performance measures, specific goals need to be set, so that we can determine when the LOPP and CERP have met their targets. Tracking progress towards these goals is straight forward, but one must establish a criterion for determining if and when a goal has been achieved. For example, given that considerable seasonal and year-to-year variation that occurs in pelagic total P, how will we know when the concentration has reached the 40 ppb goal? One approach that can be taken where a high degree of short-term noise exists in the data is to look at long-term averages, for example five-year running means. Another approach is to determine the statistical characteristics of the data (e.g., standard error, 95% confidence interval, etc.), and then determine success to occur when the goal falls within the error bounds or confidence interval of the observed data. In either case, it is important that success criteria consider that the goal is met on a continuous basis, rather than being due to some transient event that has a short-term impact on the system (e.g., a drought might result in low pelagic total P for one or two years). The criteria for judging success in this restoration Plan should be a priority topic for discussion between the SFWMD, FDEP, FDACS, and other participating agencies, local governments and NGOs.

Reporting of performance measures will follow a standardized approach, and will be done in a manner that is readily understood by resource managers, Legislators, and the general tax-paying public. The report card that recently has been developed by the CERP RECOVER program for the US Congress can provide a template for these reports. The following pages include example reports for two of the Lake Okeechobee performance measures – L2 (pelagic total phosphorus concentration) and L11 (submerged aquatic vegetation). In each case there is a simple summary graph that shows the target line, the actual data, and a brief narrative explaining the status and trends.

A report on performance measure status and trends, based on this Lake Restoration Assessment Plan, will be provided to the Florida Legislature, the coordinating agencies, and the general public on a 5 year basis, which is the timeframe for re-evaluating the lake's total phosphorus TMDL. The report will contain individual pages, formatted as in the two examples above. Report cards are not intended to summarize trends for all 20 of the performance measures listed above. Rather, they will focus on those performance measures considered key to evaluating success of the LOPP in protecting the health of Lake Okeechobee. Other measures, not included in the report, will be used in a more technical manner, as guidance to resource managers in an adaptive management framework. The key performance measures in report cards to the Legislature will include: phosphorus loading rate, lake water total phosphorus, algal bloom frequency, water clarity, acreage of submerged plants, and acreage of native vs. exotic plants in the littoral zone.

A summary table also will be developed, giving a color-coded score (green = goal achieved, yellow = performance moving toward goal, red = performance not yet improving) for each of the key performance measures, and if desired, a scoring system developed to give the ecosystem an overall score in each successive report. Havens and Rosen (1996) provide a framework that could be followed in developing this summary scoring method.

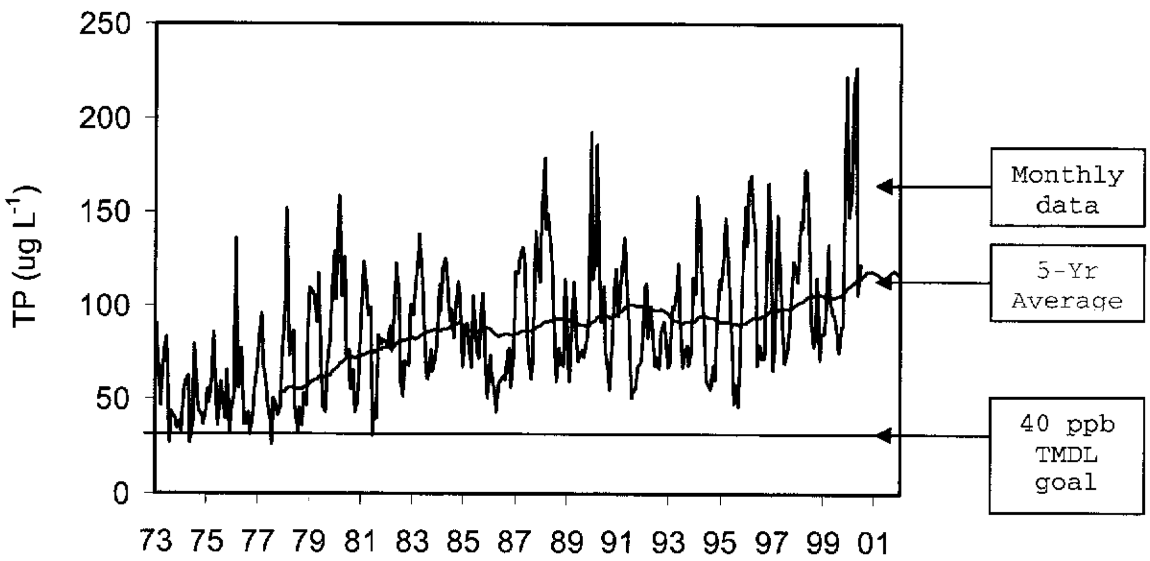
IX. Example Report Card Pages

Example Report 1 – Pelagic Total Phosphorus

LOPP Target: The target is to achieve a long-term average concentration of total phosphorus (TP) of 40 ppb in the Lake's pelagic (open-water) zone. The Florida Department of Environmental Protection has adopted this as the in-lake goal for the Total Maximum Daily Load (TMDL) for P in the Lake ecosystem.

Significance and Background: When phosphorus levels become excessive, there can be dramatic changes in plant and animal community structure in lakes, typically including increases in dominance of species that have undesirable impacts on habitat quality. Increased occurrence of noxious blue-green algae blooms is an example. These changes are been documented in Lake Okeechobee.

Status and Trends: Total P concentrations in Lake Okeechobee were near 40 to 50 ppb when first measured in the early 1970s, but have displayed an increase over the last three decades, such that concentrations now average near 100 ppb in the lake's open water region. The increase is linked with increased external P loads over the long term and with high water level in shorter (year to year) time scales.



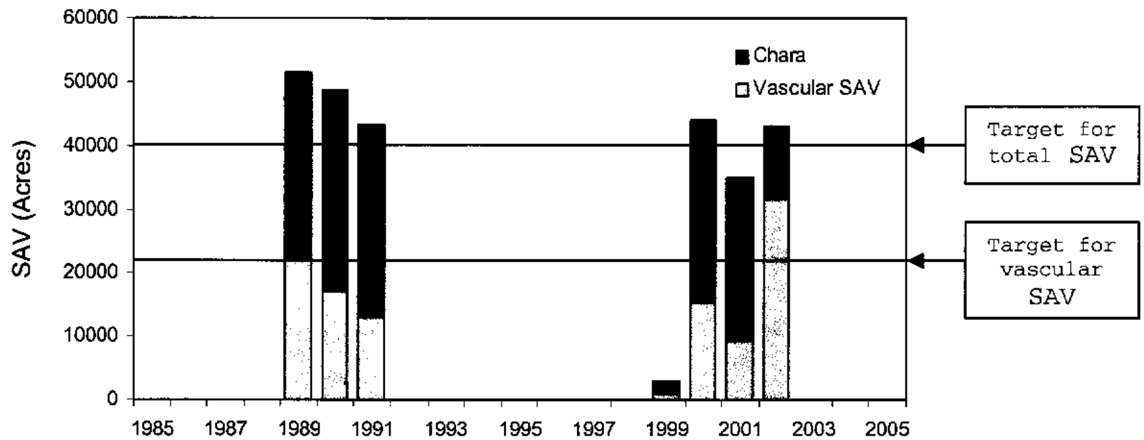
Restoration Actions / Expected Response: A variety of projects in the watershed, at regional and local scales, are being done to reduce P inputs to the lake. In-lake P control projects also are being considered. Response time for this performance measure could be in the decades, given the long history of accumulated P in the ecosystem.

Example Report 2 – Submerged Aquatic Vegetation

LOPP Target: The restoration target is to sustain at least 40,000 total acres of submerged aquatic vegetation (SAV) around the north, west, and south shoreline of the lake, with at least 20,000 acres contributed by vascular plants (in particular eelgrass, peppergrass, and southern naiad).

Significance and Background: Submerged vegetation plays a critical role in stabilizing sediments, supporting attached algae that removes phosphorus from the water, and providing critical habitat for fish, wading birds, and other wildlife. Vascular plants provide the most valuable habitat, while *Chara*, a macro-alga that is common in this and other shallow eutrophic lakes, serves to stabilize sediments but is not as useful for wildlife. Shoreline areas of Lake Okeechobee have supported a large acreage of submerged vascular plants in years with moderate to low water levels, but the acreage has been reduced to near zero following multiple years with very high water. A reduction in the occurrence of high water levels under LOPP and CERP is expected to cause widespread increases in the submerged aquatic vegetation in Lake Okeechobee.

Recent Status and Trends: When spatial extent of the submerged aquatic vegetation was measured just after a period of low lake stage in 1989-91, between 43,000 and 51,000 total acres were found. Between 13,000 and 22,000 acres were due to vascular plants, with the remainder due to *Chara*. Submerged vegetation was not sampled between 1991 and 1997. In 1998, after many years of high lake stage, a rough estimate by the Florida Fish and Wildlife Conservation Commission indicated that only 3,000 acres of total submerged vegetation remained in the lake. A detailed survey by the SFWMD in August 2000, after a managed lake recession, indicated that the community had recovered to 45,000 total acres, with over 15,000 acres due to vascular plants. In September 2001, after a severe drought and record low lake stage, there was 34,000 total acres of submerged plants, and just 9,000 acres of vascular plants. In July 2002, the spatial extent of submerged vegetation was 43,000 acres, with over 30,000 acres of vascular plants (primarily *Hydrilla*, eelgrass, coontail, southern naiad, and peppergrass).



Restoration Actions / Expected Response: The two CERP / LOPP projects that are expected to substantially affect water levels in the Lake, and hence, the biomass and spatial extent of SAV, are the regional ASR and north-of-lake reservoir projects. Regional ASR will account for most of the improvements in lake hydro-pattern (based on hydrologic model results). Since regional ASR is not scheduled for completion until after 2015, large-scale lasting improvements in SAV may not occur for some time. Until then, however, limited benefits to the SAV might be attained by adaptive management of water levels in the lake, within the constraints of the existing regional infrastructure and competing demands for water.

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